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Statistical Correlations of Surface Wind Data A Comparison between a National Weather Service Station and a Nearby Aerometric Monitoring Network

Lockheed Engineering and Management Services
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by

John E. Langstaff, Anthony D. Thrall, and Mei-Kao Liu
Systems Applications, Inc.
101 Lucas Valley Road
San Rafael, CA 94903

under subcontract to

Lockheed Engineering and Management Services Company, Inc.
P. O. Box 15027
Las Vegas, NV 89114

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Project Officer
Joseph V. Behar, Ph.D.
Exposure Assessment Research Division
Environmental Monitoring Systems Laboratory
Las Vegas, NV 89114

ENVIRONMENTAL MONITORING SYSTEMS LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
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ABSTRACT

This report presents a statistical analysis of wind data collected at a network of stations in the Southeast Ohio River Valley. The purpose of this study is to determine the extent to which wind measurements made by the National Weather Service (NWS) station at the Tri-State Airport can be used to estimate the wind measurements at network stations. A combined stratification/regression analysis was conducted. We show that NWS station measurements can be used to gain an insight into the wind measurements at network stations, and we identify a methodology for carrying this out. With this methodology, we demonstrate that the wind data collected at the airport can be used to provide input to a complex-terrain wind model for estimating the surface winds in the study area for periods prior to the establishment of the monitoring network.

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Suggestions from, and discussion with, many individuals have served to focus our attention on the interesting and challenging problem addressed in this report. In addition, these comments helped to determine the final approach adopted in the present study. In this regard, we would like to gratefully acknowledge the suggestions of Drs. Joseph Behar, George Flatman, Robert Schonbrod, and James McElroy from the Environmental Monitoring Systems Laboratory, Las Vegas, of the U.S. Environmental Protection Agency, and of Mr. Michael Pearson from Lockheed Engineering and Management Services Co., Inc.

SECTION 1

INTRODUCTION

The monitoring of human exposure to toxic and hazardous chemicals released into the environment can be an expensive and time-consuming effort. Because of the multifaceted nature of exposure assessment studies, it is essential to carefully plan the deployment of the monitoring system to meet stated objectives. Otherwise, the data collected may contain uncertainties large enough to render the data useless. Recently, a field measurement program has been conducted by the Environmental Monitoring Systems Laboratory, Las Vegas, of the U.S. Environmental Protection Agency in the Southeast Ohio River Valley to support the development of a second-generation methodology for the design of an exposure assessment monitoring network (Richitt et al., 1982). This area was selected both because of observed elevated levels of several pollutant species in this area, such as benzo(a)pyrene, that are suspected carcinogens, and because a lung cancer control study was being considered for this area.

As part of this study, a statistical analysis of the wind flow field in the Southeast Ohio River Valley was carried out. The primary goal was to perform an analysis of wind measurements collected by the National Weather Service (NWS) at the Tri-State Airport and those collected at twelve network stations during the field study sponsored by the Environmental Monitoring Systems Laboratory. Weather observations from the NWS station at the Tri-State Airport constitute a long history of continuous records. Compiled from twelve additional wind stations in the study area, the field study data provide detailed spatial coverage, but only for a relatively short time period that may not be long enough for the assessment of human exposure to highly latent carcinogens. Therefore, the first objective of this study is to examine the correlation, if any, between the NWS wind measurements and those made at other locations.

Once the existence of a statistically significant correlation between data measurements made at the Tri-State Airport and those made at other stations is established, NWS wind data collected at the Tri-State Airport can be utilized to derive wind patterns in prior years. The approach outlined above is illustrated in Figure 1-1. With the combined use of the airport data and the network data, wind measurements reported at the airport in prior years may be enhanced in information content by diurnal and/or seasonal wind patterns. These synthesized wind patterns can then be used in a complex-terrain wind model to reproduce the detailed spatial distributions of the wind field. The wind field, a prerequisite in any air quality analysis, can be used in subsequent exposure assessment studies. The data base used to accomplish these goals is discussed in Section 2. Section 3 describes the

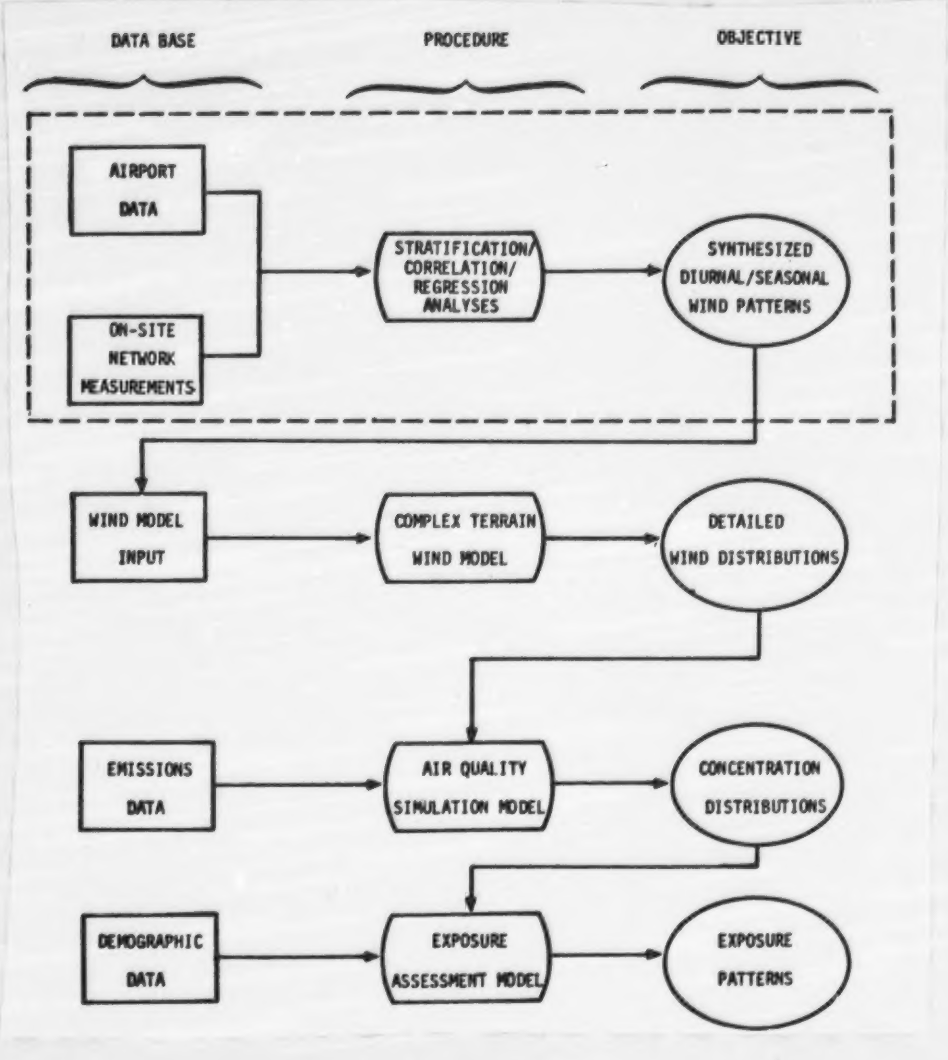
DATA BASE
PROCEDURE
OBJECTIVE
AIRPORT DATA
ON-SITE NETWORK MEASUREMENTS
STRATIFICATION/ CORRELATION/ REGRESSION ANALYSES
SYNTHESIZED DIURNAL/SEASONAL WIND PATTERNS
WIND MODEL INPUT
COMPLEX TERRAIN WIND MODEL
DETAILED WIND DISTRIBUTIONS
EMISSIONS DATA
AIR QUALITY SIMULATION MODEL
CONCENTRATION DISTRIBUTIONS
DEMOGRAPHIC DATA
EXPOSURE ASSESSMENT MODEL
EXPOSURE PATTERNS

Figure 1-1. Utilization of airport data to retrieve wind/air quality patterns in an Exposure Assessment Study (topics addressed in this report circled by dotted lines).

methodology used and presents the results of the statistical analyses. A summary and recommendations for further analysis are presented in Section 4. Appendices A through E contain detailed graphical information regarding wind vectors in the study area and the results of the statistical analysis presented in Section 3. Details of the recommendations discussed in Section 4 are presented in Appendix F.

SECTION 2

DESCRIPTION OF THE DATA BASE

As indicated in the introduction, the Southeast Ohio River Valley was selected as the study area to demonstrate a rationale and approach for the design of a monitoring network for human exposure assessments. We first present a brief description of this area, followed by a discussion of the meteorological data base that was collected in this area and used in the subsequent statistical and modeling analyses.

THE STUDY AREA

The study area shown in Figure 2-1 encompasses the tri-state juncture of West Virginia, Kentucky, and Ohio along the Ohio River; the area covers more than 250 square miles containing approximately 160,000 people and includes major population centers such as Huntington, Ashland, and Ironton.

For the purpose of digitizing terrain data, the study area was divided into a 40 x 33 grid consisting of cells that are 1 km by 1 km in size. The origin of the grid was placed at 347000E and 4243000N in zone 17 of the UTM coordinates, with the latitudinal axis extending from west to east and the longitudinal axis extending from south to north. The average height of terrain above sea level for each cell was computed from digitized terrain data provided by the U.S. Geological Survey (USGS). The locations of major landmarks such as rivers, towns, and highways were obtained from a USGS 1:250000-scale map of the quadrangle that included Ironton, Ohio; Huntington, West Virginia; and Ashland, Kentucky. Figure 2-2 shows this grid with terrain contours at 100-foot intervals and with major cities shaded in light gray. Also displayed in this figure are the Ohio River and one of its tributaries, the Big Sandy River.

THE AEROMETRIC MONITORING NETWORK

As part of the development of second-generation approaches to exposure assessment monitoring, aerometric data were collected in the Southeast Ohio River Valley study area. These data and the data available through the National Weather Serivce constitute the primary data base for the present analyses.

Wind monitoring stations were installed at twelve sites in the Ohio Valley. The names and coordinates of the twelve sites are listed in Table 2-1. The location of the wind stations, including the National Weather

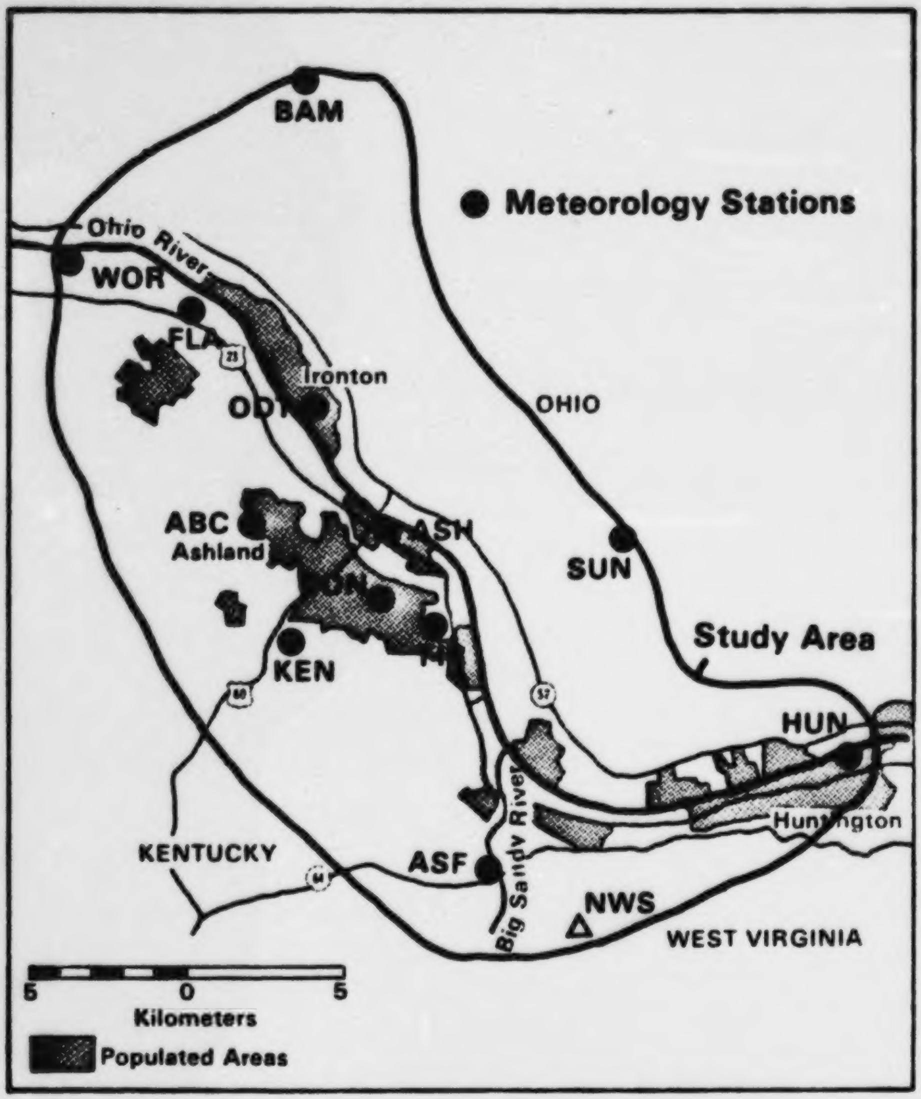
BAM
● Meteorology Stations
Ohio River
WOR
FLA
23
Ironton
ODT
OHIO
ABC
Ashland
ASH
SUN
KEN
Study Area
60
52
HUN
Huntington
Big Sandy River
KENTUCKY
ASF
64
NWS
WEST VIRGINIA
5
0
5
Kilometers
▨ Populated Areas

Figure 2-1. Monitoring network in the study area--Southeast Ohio River Valley. Dark circles identify the locations of the 12 EPA wind monitoring stations.

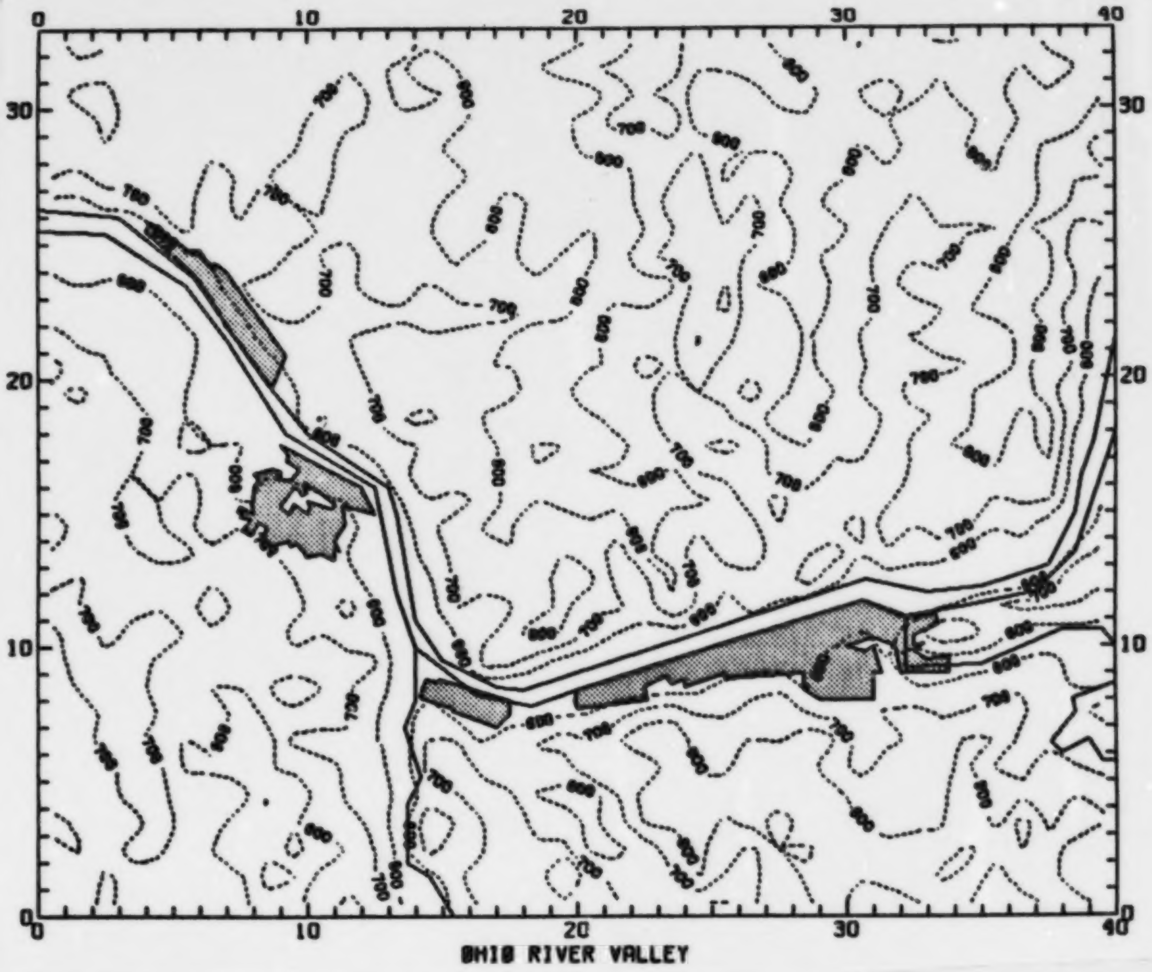
0
10
20
30
40
600
700
800
OHIO RIVER VALLEY

Figure 2-2. Topography of the study area. Contours are given as feet above MSL. Abcissa and Ordinate represent 1 km grid ticks.

TABLE 2-1. NAMES AND COORDINATES OF METEOROLOGICAL STATIONS

Site	UTM Coordinates	
	East	North
Ashland Business College (ABC)	353,841	4,260,707
Ashland Synthetic Fuels (ASF)	360,049	4,249,390
Ashland City Building (ASH)	357,195	4,259,951
Bamer Residence (BAM)	355,458	4,273,024
Condit Elementary School (CON)	356,915	4,257,829
Fire Station No. 2 (FIR)	359,756	4,255,098
Flatwoods (FLA)	352,012	4,266,646
Huntington Water Corporation (HUN)	376,500	4,254,412
KEN Department of Human Resources (KEN)	354,524	4,257,122
Ohio Department of Transportation (ODT)	355,049	4,263,500
Sunrise Hill (SUN)	365,500	4,260,085
Worthington (WOR)	348,670	4,268,183
Tri-States Airport (NWS)	363,750	4,247,500

Service station at the Tri-State Airport, is displayed in Figure 2-1. For each of these twelve sites, hourly average wind speeds and directions and their standard deviations were computed from instantaneous observations collected every two minutes. The data used in this analysis covered the period from 1 February 1980 through 28 February 1981, with the exception of those time periods for which data were missing.

Table 2-2 summarizes the 1980-1981 time periods with available data for these twelve sites. The distribution of wind speeds and directions for these sites, plotted as wind roses, is presented on a monthly basis in Appendix A. The distribution for each station is plotted at its actual location on the grid described earlier. The label on the outer ring encircling each station indicates the percentage of readings in a bar when that bar touches the ring. Each bar extends in the direction from which the winds included in that bar are blowing. Wind speeds are divided into three categories: under 1 m/sec, 1-5 m/sec, and over 5 m/sec. The percentage of hours of winds under 1 m/sec winds appears inside the inner ring. The percentage of winds between 1 and 5 m/sec is proportional to the length of the unshaded portion of a bar. The percentage of winds over 5 m/sec is proportional to the length of the shaded portion of the bar.

The data obtained from the National Weather Service were digitized from microfiche. These data provide 1-minute average values of wind speed and direction at hourly intervals taken approximately 10 minutes before the hour at the Tri-State Airport near Huntington, West Virginia. The data from adjacent hours are averaged to provide the hourly average values used in the analysis. The percentage of missing data at this site is very small (generally less than 2 percent).

TABLE 2-2. AN INVENTORY OF WIND DATA COLLECTED AT SOUTHEAST OHIO RIVER VALLEY (PERCENT RECOVERY)

Station	1980											1981	
	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.
ABC	12	89	71	89	0	29	95	59	68	9	0	24	25
ASF	0	0	0	0	0	0	0	0	0	0	0	56	98
ASH	0	39	17	0	0	0	0	0	0	0	0	72	95
BAM	11	58	61	90	98	6	0	0	27	75	0	56	96
CON	0	43	53	91	76	26	0	0	71	47	0	79	94
FIR	0	44	51	77	83	67	82	53	89	74	0	82	47
FLA	32	96	75	94	99	66	88	82	39	23	0	0	0
HUN	0	0	0	0	0	64	83	91	89	68	0	67	96
KEN	18	89	57	81	99	61	92	98	96	77	0	82	100
ODT	32	73	51	93	98	36	91	48	96	77	0	75	84
SUN	0	0	0	0	0	0	0	14	85	74	0	33	69
WOR	46	94	74	93	93	40	0	0	55	10	0	74	99
NWS	100	100	100	100	100	100	100	100	100	100	100	100	100

Although there is a substantial amount of data missing at the monitoring stations, this does not significantly affect the analysis we have performed since it is not a time series analysis, but instead uses simultaneous data points without regard to their order. However, if this analysis was performed for each season, some stations might not have sufficient data for all seasons.

SECTION 3

STATISTICAL ANALYSIS OF METEOROLOGICAL DATA

As indicated in the introduction, the objectives of the present statistical analysis are

- To determine the correlation between the wind measurements collected at the Tri-State Airport (NWS) and wind measurements collected by the special meteorological network.
- To ascertain the feasibility of estimating winds at the network station locations using the NWS data alone.

Two types of analyses were carried out to examine the relationship between wind measurements collected at different monitoring sites, particularly the relationship between the NWS data collected at the Tri-State Airport and data measured by other stations in the network. First, we conducted an analysis of the correlation between stations using the full data set. Second, after the data were stratified by wind direction into bins, a regression analysis was performed (1) to determine the correlation of NWS stations measurements with the measurements taken at the other twelve stations and (2) to provide a procedure for calculating the winds at these twelve stations.

CORRELATION ANALYSIS

To provide quantitative information concerning the consistency of the relationships between all the stations, correlations were calculated for each pair of stations using the full set of data for wind speed, wind direction, and the u and v rectangular components of wind velocity (Table 3-1). u and v are defined by the transformations

$$\begin{aligned} u &= U \cos \theta \\ v &= U \sin \theta \quad , \end{aligned} \qquad (3\text{-}1)$$

where U is the wind speed and θ is the wind direction. An X in these tables indicates that we were unable to perform correlations because there were no overlapping data at that pair of stations.

TABLE 3-1. INTERSTATION CORRELATIONS
(a) Wind Speed

STATION	ABC	ASF	ASH	BAM	CON	FIR	FLA	HUN	KEN	DDT	SUN	WOR	NMS
ABC	1.00												
ASF	0.66	1.00											
ASH	0.71	0.63	1.00										
BAM	0.67	0.69	0.83	1.00									
CON	0.65	0.69	0.83	0.73	1.00								
FIR	0.51	0.52	0.53	0.56	0.53	1.00							
FLA	0.69	X	0.83	0.86	0.76	0.59	1.00						
HUN	0.72	0.63	0.76	0.81	0.68	0.53	0.71	1.00					
KEN	0.71	0.63	0.76	0.78	0.76	0.47	0.77	0.67	1.00				
DDT	0.68	0.70	0.76	0.79	0.83	0.60	0.85	0.76	0.72	1.00			
SUN	0.57	0.54	0.75	0.76	0.38	0.30	0.46	0.65	0.72	0.47	1.00		
WOR	0.69	0.59	0.77	0.77	0.83	0.51	0.86	0.73	0.70	0.83	0.36	1.00	
NMS	0.70	0.66	0.70	0.79	0.76	0.55	0.77	0.78	0.77	0.76	0.63	0.75	1.00

TABLE 3-1. (Continued)

Interstation Correlations
(b) Wind Direction

STATION	ABC	ABF	ABH	BAM	CON	FIR	FLA	HUN	KEN	ODT	SUN	WOR	NWS
ABC	1.00												
ABF	0.34	1.00											
ABH	0.34	0.36	1.00										
BAM	0.85	0.37	0.62	1.00									
CON	0.79	0.43	0.75	0.69	1.00								
FIR	0.93	0.53	0.73	0.88	0.93	1.00							
FLA	0.81	X	0.40	0.85	0.78	0.82	1.00						
HUN	0.41	0.59	0.34	0.60	0.39	0.55	0.57	1.00					
KEN	0.70	0.39	0.71	0.71	0.83	0.88	0.81	0.47	1.00				
ODT	0.71	0.43	0.60	0.78	0.49	0.79	0.85	0.51	0.51	1.00			
SUN	0.62	0.25	0.86	0.64	0.73	0.70	0.85	0.42	0.65	0.40	1.00		
WOR	0.63	0.35	0.32	0.43	0.57	0.53	0.54	0.30	0.47	0.51	0.61	1.00	
NWS	0.59	0.48	0.52	0.69	0.64	0.73	0.67	0.42	0.66	0.59	0.61	0.63	1.00

TABLE 3-1. (Continued)

Interstation Correlations
(c) u

STATION	ABC	ABF	ABH	BAM	CON	FIR	FLA	HUN	KEN	ODT	SUN	WOR	NMS
ABC	1.00												
ABF	0.67	1.00											
ABH	0.64	0.74	1.00										
BAM	0.75	0.77	0.79	1.00									
CON	0.82	0.77	0.80	0.81	1.00								
FIR	0.80	0.70	0.78	0.85	0.85	1.00							
FLA	0.76	X	0.54	0.89	0.79	0.86	1.00						
HUN	0.70	0.70	0.75	0.71	0.76	0.76	0.72	1.00					
KEN	0.82	0.75	0.81	0.86	0.86	0.81	0.80	0.69	1.00				
ODT	0.79	0.67	0.79	0.84	0.85	0.88	0.88	0.74	0.81	1.00			
SUN	0.52	0.72	0.89	0.86	0.68	0.71	0.72	0.62	0.78	0.60	1.00		
WOR	0.76	0.48	0.54	0.64	0.71	0.72	0.79	0.64	0.67	0.70	0.33	1.00	
NMS	0.74	0.74	0.72	0.80	0.79	0.78	0.73	0.70	0.84	0.78	0.75	0.61	1.00

TABLE 3-1. (Continued)

Interstation Correlations
(d) v

STATION	ABC	ABF	ASH	BAM	CON	FIR	FLA	HUN	KEN	ODT	SUN	WOR	NWS
ABC	1.00												
ABF	0.62	1.00											
ASH	0.66	0.52	1.00										
BAM	0.87	0.63	0.78	1.00									
CON	0.78	0.60	0.83	0.84	1.00								
FIR	0.60	0.39	0.60	0.64	0.58	1.00							
FLA	0.82	X	0.70	0.88	0.76	0.60	1.00						
HUN	0.78	0.62	0.87	0.90	0.77	0.46	0.70	1.00					
KEN	0.85	0.60	0.80	0.93	0.80	0.60	0.84	0.85	1.00				
ODT	0.79	0.56	0.78	0.86	0.82	0.49	0.88	0.83	0.81	1.00			
SUN	0.69	0.56	0.83	0.85	0.64	0.37	0.33	0.82	0.84	0.62	1.00		
WOR	0.81	0.51	0.81	0.84	0.85	0.61	0.91	0.80	0.82	0.84	0.63	1.00	
NWS	0.80	0.61	0.67	0.87	0.75	0.49	0.76	0.85	0.87	0.81	0.81	0.78	1.00

The sample correlation between two stations is given by

$$\rho_{xy} = \frac{\frac{1}{N-1} \sum_{i=1}^{N} (X_i - \overline{X})(Y_i - \overline{Y})}{s_x s_y} \quad , \qquad (3\text{-}2)$$

where X_i and Y_i, $i=1, \ldots, N$, are the data from stations x and y, including only values that are simultaneously valid. For the wind direction calculations, data are not used if the wind speed is below 1.1 m/s. $\overline{X}$ and $\overline{Y}$ are the sample mean values

$$\overline{X} = \frac{1}{N} \sum_{i=1}^{N} X_i \quad ,$$

$$\overline{Y} = \frac{1}{N} \sum_{i=1}^{N} Y_i \quad . \qquad (3\text{-}3)$$

s_x and s_y are the sample standard deviations,

$$s_x = \sqrt{\frac{1}{N-1} \sum_{i=1}^{N} (X_i - \overline{X})^2}$$

$$s_x = \sqrt{\frac{1}{N-1} \sum_{i=1}^{N} (Y_i - \overline{Y})^2} \quad . \qquad (3\text{-}4)$$

Furthermore, a linear regression analysis of the NWS station was done for each of the twelve network stations. The results of this regression analysis for wind speed, direction, u, and v are given in Table 3-2. The coefficients of the regression equation

$$Y = \alpha X + \beta \quad , \qquad (3\text{-}5)$$

TABLE 3-2. REGRESSION RESULTS FOR EACH NETWORK STATION, BASED ON NWS STATION DATA

(a) Wind Speed

STATION	CORRELATION	SLOPE	INTERCEPT	MEAN	STANDARD DEVIATION
ABC	0.70	0.71	-0.12	2.1	1.60
ASF	0.66	0.57	0.34	2.4	1.39
ASH	0.70	0.85	-0.53	2.5	1.91
BAM	0.79	0.49	-0.11	1.5	1.00
CON	0.76	0.89	-0.38	2.4	1.84
FIR	0.55	0.37	-0.06	1.0	1.02
FLA	0.77	0.78	-0.56	1.8	1.60
HUN	0.78	0.65	-0.27	1.6	1.20
KEN	0.77	0.70	0.54	2.7	1.43
ODT	0.76	0.62	0.15	2.1	1.28
SUN	0.63	0.65	1.09	3.2	1.63
WOR	0.75	0.81	-0.37	2.3	1.76

(b) Wind Direction

STATION	SLOPE	INTERCEPT
ABC	1.00	-11.00
ASF	1.00	1.74
ASH	1.00	-13.05
BAM	1.00	0.22
CON	1.00	-16.55
FIR	1.00	-13.50
FLA	1.00	-7.00
HUN	1.00	-6.37
KEN	1.00	-5.09
ODT	1.00	-8.66
SUN	1.00	14.94
WOR	1.00	-22.59

TABLE 3-2. (Continued)

TABLE 3-2. (Continued)

(c) u

STATION	CORRELATION	SLOPE	INTERCEPT	MEAN	STANDARD DEVIATION
ABC	0.75	0.59	−0.34	−0.5	1.80
ASF	0.74	0.61	0.09	−0.1	1.90
ASH	0.72	0.52	0.01	−0.1	1.73
BAM	0.80	0.37	0.06	0.1	1.09
CON	0.79	0.69	−0.12	−0.2	1.98
FIR	0.81	0.51	0.07	−0.0	1.47
FLA	0.74	0.49	0.21	0.1	1.52
HUN	0.70	0.40	0.11	−0.0	1.25
KEN	0.84	0.74	−0.22	−0.4	2.01
ODT	0.78	0.55	0.20	0.1	1.60
SUN	0.75	0.71	−0.26	−0.4	2.25
WOR	0.61	0.45	−0.01	−0.1	1.71

(d) v

STATION	CORRELATION	SLOPE	INTERCEPT	MEAN	STANDARD DEVIATION
ABC	0.80	0.55	−0.36	−0.8	1.73
ASF	0.61	0.35	−0.64	−1.1	1.65
ASH	0.67	0.58	−0.22	−0.8	2.54
BAM	0.87	0.44	−0.11	−0.5	1.40
CON	0.75	0.66	−0.07	−0.7	2.25
FIR	0.52	0.13	0.21	0.1	0.63
FLA	0.76	0.57	−0.10	−0.5	1.87
HUN	0.85	0.56	−0.07	−0.4	1.57
KEN	0.87	0.74	−0.24	−0.8	2.15
ODT	0.81	0.59	0.09	−0.4	1.81
SUN	0.81	0.80	−0.24	−1.1	2.65
WOR	0.78	0.65	−0.02	−0.6	2.26

TABLE 3-2. (Concluded)

are defined by

$$\alpha = \rho_{xy} \frac{s_y}{s_x} \quad , \tag{3-6}$$

$$\beta = \overline{Y} - \alpha\overline{X} \quad . \tag{3-7}$$

Appendix B presents figures of the regression lines superimposed over scatter plots of the data.

The wind direction statistics are calculated in a different way since direction is circular, and 0° is equivalent to 360°. The usual regression formulation has been modified in the case of wind directions by constraining the slope coefficient α to equal unity. This is necessary for the regression scheme to be well defined. For example, suppose that $\alpha = 0.5$ and $\beta = 0.0$; then, if $X = 0$, $Y = \alpha X + \beta = 0$, and if $X = 360$, $Y = 180$; therefore, we have different predicted values for $X = 0$ and $X = 360$. Use of $\alpha = 1$ results in a wind direction regression model with a single-shift parameter β. This parameter β is then determined by minimization of the squared deviations

$$Q = \sum_{i=1}^{N} (\tilde{\theta}_i - \alpha\theta_i - \beta)^2 \quad , \tag{3-8}$$

with $\alpha = 1$. These differences are constrained to be in the interval [-180°, 180°]. This value of β produces the least-squares fit to the data from the equation (Bendat and Piersol, 1971).

$$\tilde{\theta} = \theta + \beta \tag{3-9}$$

The mean value $\overline{\theta}$ is calculated in the following way: First an approximation $\overline{\theta}'$ of the mean value is calculated by the vector average of unit vectors ($\cos\theta$, $\sin\theta$)

$$\overline{\theta}' = \arctan \frac{1}{N} \sum_{i=1}^{N} \sin\theta_i \Big/ \frac{1}{N} \sum_{i=1}^{N} \cos\theta_i \quad . \tag{3-10}$$

Each θ_i is adjusted by adding a multiple of 360° so that $|\theta_i - \bar{\theta}'| \leq 180°$. The mean value is then given by

$$\bar{\theta} = \frac{1}{N} \sum_{i=1}^{N} \theta_i \quad . \tag{3-11}$$

The mean value of the independent variable θ is calculated using Equation (3-9), which gives

$$\bar{\tilde{\theta}} = \bar{\theta} + \beta \quad , \tag{3-12}$$

Since $\alpha = 1$. Equations (3-2) and (3-4) give $\rho_{\theta\tilde{\theta}}$, where each difference is constrained to lie in the interval $[-180, 180]^{\theta\theta}$.

The NWS wind speeds are reported as 1 minute averages to the nearest knot and the directions every ten degrees. These data have been randomized for the scatter plots by adding to each NWS wind speed a random number uniformly distributed in the interval -0.5 to +0.5 knots, and adding to each NWS wind direction a random number uniformly distributed in the interval -5 to +5 degrees. If this is not done, the data are grouped into vertical lines on the plots and the true density of the points is obscured because of the large number of points being plotted. The data at other stations is reported with finer resolution so no randomization is performed for these data. This randomization is done only when displaying the data by scatter plots, and not for any of the statistical calculations.

A generally high degree of correlation is evident in Table 3-2 between station variables and corresponding NWS variables; this indicates that prediction errors can be significantly reduced by regressing the station wind field on NWS measurements, rather than by estimating the wind field solely on the basis of station averages. In the next section, we demonstrate that further gains are possible when we stratify the data.

STRATIFICATION AND REGRESSION ANALYSIS

In this part of the analysis, we present a methodology for relating wind speed and direction at the twelve network stations using corresponding data from the NWS station. This methodology consists of two parts: First, the data are stratified into bins on the basis of the NWS wind speed and direction (see Table 3-3). Then, for each of the 12 network stations and for each of the bins, a linear regression is performed using the NWS wind speed and direction as independent (predictor) variables. This methodology, i.e., data stratification followed by separate linear regressions within each stratum

TABLE 3-3. STATISTICS FOR WIND DIRECTION STRATIFICATION

	BIN NO.	WIND DIRECTION	OCCURRENCES	FREQUENCY
WIND SPEED > 1.1 m/s	1	2.50 TO 22.50	314	0.033
	2	22.50 TO 42.50	324	0.034
	3	42.50 TO 62.50	438	0.046
	4	62.50 TO 82.50	445	0.047
	5	82.50 TO 102.50	352	0.037
	6	102.50 TO 122.50	440	0.047
	7	122.50 TO 142.50	366	0.039
	8	142.50 TO 162.50	311	0.033
	9	162.50 TO 182.50	357	0.038
	10	182.50 TO 202.50	579	0.061
	11	202.50 TO 222.50	1064	0.113
	12	222.50 TO 242.50	733	0.078
	13	242.50 TO 262.50	600	0.063
	14	262.50 TO 282.50	595	0.063
	15	282.50 TO 302.50	390	0.041
	16	302.50 TO 322.50	376	0.040
	17	322.50 TO 342.50	470	0.050
	18	342.50 TO 2.50	421	0.045
CALM	19		875	0.093

(bin), was adopted in an attempt to improve the performance of the linear model. It is anticipated that the complex terrain of the study region might cause the global linear model using unstratified data to yield poor results. For example, if a particular station's measurements within a bin cluster tightly around a certain value, e.g., the mean value of the cluster, then this value can be predicted with a fair degree of reliability when the NWS measurement falls into that bin. In general, a tighter cluster should yield more reliable predictions.

The predicted values are obtained using the regression equations for each bin. The root-mean-square error (RMSE) (the standard deviation of the residuals) and the interquartile range (the range between the lower and upper quartiles of the residuals) provide measures of the spread of the observed values about the predicted values. For the prediction to be reliable, there must be a sufficient number of measurements in each bin. This puts a constraint on the number of bins we can use; that is, if there are too many bins, there will be too few measurements within some of the bins.

The linear models used within each bin can have different forms. We have chosen to perform the regression in polar coordinates, since this method treats a linear relationship between the wind speeds and a simple shift relationship between the wind directions at the station pairs. This situation can arise when the wind flow is channeled by the valley. For example, if the wind is from the east at station HUN, channeling can produce winds from the southeast at station ASH, with proportional wind speeds at the HUN and ASH stations. Alternatively, the Cartesian coordinates u and v could be used. In this case Equations (3-1) through (3-6), for u and v separately, provide the linear model. A third method is to utilize complex variables. This is outlined in Appendix F.

For this analysis, the data are stratified on the basis of the NWS wind direction using 18 compass points. Since differentiation of wind directions under calm conditions is not meaningful, we formed an additional 19th bin corresponding to calm NWS conditions. Table 3-3 shows the total number of hourly measurements within each of the 18 bins. The data flow for this analysis is outlined in Figure 3-1. Stratification of the data is depicted graphically in Appendix C using wind roses for each station, with one figure for each NWS wind direction bin. Inspection of these figures indicates that at least qualitatively, the wind directions measured at other stations follow a pattern corresponding to the wind direction measured by the National Weather Service at Tri-State Airport for all cases other than calm conditions. The correlation and linear regression coefficients relating each monitoring station to the NWS station are calculated within each bin for both wind speed and direction, using Equations (3-1) through (3-11).

Regression results for each station are given in Appendix D. The regression coefficients, interquartile ranges, and RMS errors are tabulated by bin and stations in Table 3-4. The interquartile range is the range between the lower and upper quartiles of the speed and direction residuals, and the combined standard error is the RMS error of the residuals or orthogonal wind velocity components u and v combined:

$$\text{combined standard error} = \sqrt{\frac{1}{2}\left(\frac{1}{N}\sum_{i=1}^{N} R_{ui}^{2} + \frac{1}{N}\sum_{i=1}^{N} R_{vi}^{2}\right)} \quad , \qquad (3\text{-}13)$$

where R_{ui}, R_{vi} are the residuals of u and v, respectively. Smaller numbers indicate a better fit to the data. In Appendix E, the predicted wind vectors for each bin are plotted at the station locations to facilitate the analysis of the effects of terrain on the wind field. In the case of calm winds at the NWS station, we use as our predicted values the average values for u and v in the calm bin at each station (Table 3-5).

REMARKS CONCERNING INDIVIDUAL STATION CHARACTERISTICS

Some qualitative observations can be made regarding results of the bin analysis. In this section, we discuss these results as they pertain to the characteristics of individual stations. More general characteristics are discussed in the following section. Results indicate that the ASF station experienced a sudden shift in the direction of the predicted wind vector from

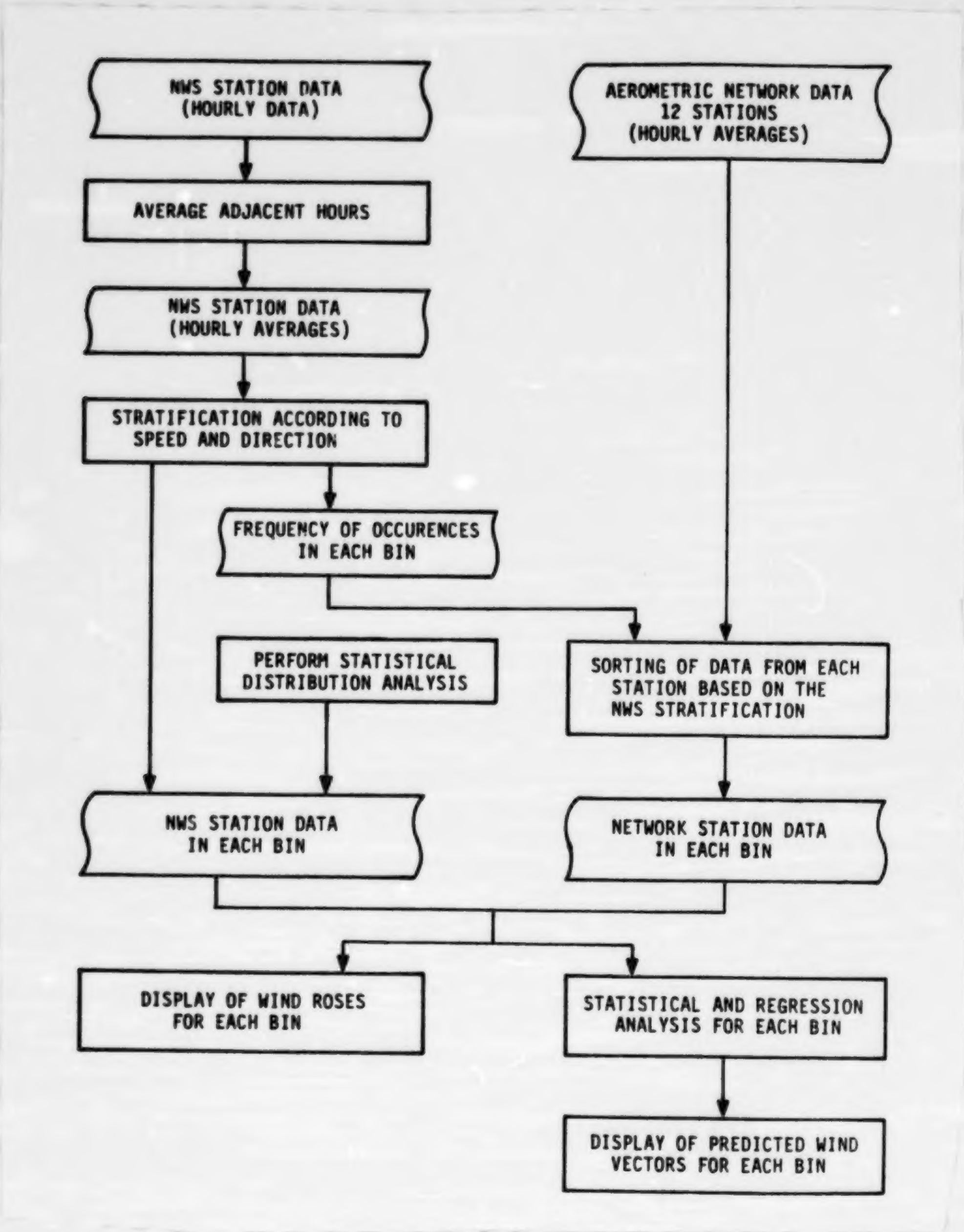
NWS STATION DATA (HOURLY DATA)
AVERAGE ADJACENT HOURS
NWS STATION DATA (HOURLY AVERAGES)
STRATIFICATION ACCORDING TO SPEED AND DIRECTION
FREQUENCY OF OCCURENCES IN EACH BIN
PERFORM STATISTICAL DISTRIBUTION ANALYSIS
NWS STATION DATA IN EACH BIN
AEROMETRIC NETWORK DATA 12 STATIONS (HOURLY AVERAGES)
SORTING OF DATA FROM EACH STATION BASED ON THE NWS STRATIFICATION
NETWORK STATION DATA IN EACH BIN
DISPLAY OF WIND ROSES FOR EACH BIN
STATISTICAL AND REGRESSION ANALYSIS FOR EACH BIN
DISPLAY OF PREDICTED WIND VECTORS FOR EACH BIN

Figure 3-1. Flow chart of data processing and data analysis.

TABLE 3-4. REGRESSION COEFFICIENTS, INTERQUARTILE RANGES, AND RMS ERRORS BY BIN AND STATION

(a) Wind speed regression slopes

BIN NO.	WIND DIRECTION	ABC	ABF	ASH	BAM	CON	FIR	FLA	HUN	KEN	ODT	SUN	WOR
1--------	2.50 TO 22.50	0.86	0.42	0.49	0.39	0.69	0.73	0.51	0.46	0.75	0.36	0.37	0.62
2--------	22.50 TO 42.50	0.69	0.69	0.53	0.41	0.55	0.75	0.65	0.51	0.83	0.55	0.36	0.71
3--------	42.50 TO 62.50	0.81	0.54	0.58	0.46	0.59	0.64	0.76	0.46	0.78	0.53	0.38	0.90
4--------	62.50 TO 82.50	0.62	0.68	0.82	0.47	0.70	0.48	0.65	0.49	0.81	0.44	0.33	0.91
5--------	82.50 TO 102.50	0.72	0.63	0.56	0.44	0.70	0.38	0.62	0.36	0.80	0.42	0.16	0.85
6-------	102.50 TO 122.50	0.63	0.21	1.15	0.57	0.80	0.50	0.81	0.44	0.82	0.45	1.23	0.87
7-------	122.50 TO 142.50	0.79	0.53	0.93	0.54	0.78	0.85	0.89	0.49	0.74	0.66	0.97	0.66
8-------	142.50 TO 162.50	0.84	0.95	1.05	0.63	1.03	0.94	0.91	0.64	0.83	0.85	1.00	0.67
9-------	162.50 TO 182.50	0.70	0.88	0.93	0.63	0.93	0.80	0.67	0.85	0.77	0.73	1.04	0.48
10-------	182.50 TO 202.50	0.80	0.67	0.68	0.46	0.94	0.69	0.68	0.78	0.66	0.74	0.57	0.63
11-------	202.50 TO 222.50	0.92	0.82	0.93	0.40	1.28	0.60	0.73	0.86	0.69	0.79	0.56	0.87
12-------	222.50 TO 242.50	1.22	0.53	0.67	0.42	1.20	0.40	0.71	0.76	0.61	0.82	0.56	1.05
13-------	242.50 TO 262.50	1.05	0.63	0.96	0.45	0.93	0.21	0.78	0.63	0.62	0.68	0.81	1.01
14-------	262.50 TO 282.50	0.55	0.51	0.61	0.53	0.83	0.09	0.88	0.78	0.70	0.70	0.89	0.88
15-------	282.50 TO 302.50	0.54	0.48	1.35	0.49	0.99	0.19	0.91	0.81	0.76	0.65	0.89	0.85
16-------	302.50 TO 322.50	0.70	0.53	1.27	0.59	1.10	0.50	1.11	0.69	0.95	0.73	0.71	0.91
17-------	322.50 TO 342.50	0.62	0.77	0.92	0.51	0.90	0.64	0.77	0.56	0.76	0.65	0.70	0.89
18-------	342.50 TO 2.50	0.56	0.49	0.73	0.51	1.08	0.77	0.58	0.47	0.62	0.66	0.38	0.68
19-------	CALM CONDITIONS*												
	AVERAGE:	0.76	0.61	0.85	0.49	0.89	0.56	0.76	0.61	0.75	0.64	0.66	0.80

* The 19th bin (calm conditions) corresponds to NWS wind speeds of less than 1.1 m/s, for which the NWS wind direction is indeterminate.

TABLE 3-4. (Continued)

(b) Wind speed regression intercepts

BIN NO.	WIND DIRECTION	ABC	ABF	ASH	BAM	CON	FIR	FLA	HUN	KEN	ODT	SUN	WOR
1	2.50 TO 22.50	-0.81	0.67	0.37	-0.07	-0.11	-0.56	-0.06	-0.05	0.16	0.21	1.20	0.01
2	22.50 TO 42.50	-0.35	0.18	0.30	-0.09	0.15	-0.75	-0.59	-0.13	-0.03	0.10	1.31	-0.21
3	42.50 TO 62.50	-0.56	0.05	-0.12	-0.09	0.04	-0.68	-0.81	0.07	0.18	0.25	1.59	-0.81
4	62.50 TO 82.50	-0.12	-0.31	-0.86	-0.04	-0.30	-0.39	-0.60	-0.02	0.05	0.33	1.59	-0.85
5	82.50 TO 102.50	-0.60	-0.28	-0.08	0.05	-0.45	-0.30	-0.51	0.26	-0.02	0.37	2.29	-0.65
6	102.50 TO 122.50	-0.36	0.70	-0.97	-0.32	-0.35	-0.50	-0.91	0.00	0.11	0.31	0.00	-0.52
7	122.50 TO 142.50	-0.65	0.12	-0.37	-0.26	-0.12	-1.10	-0.90	-0.11	0.30	-0.09	0.63	-0.11
8	142.50 TO 162.50	-0.71	-0.77	-0.64	-0.45	-0.58	-1.08	-0.73	-0.38	-0.05	-0.34	0.41	-0.01
9	162.50 TO 182.50	-0.40	0.14	-0.29	-0.48	-0.48	-0.97	-0.23	-0.86	0.31	-0.13	0.27	0.17
10	182.50 TO 202.50	-0.40	0.65	-0.10	-0.20	-0.51	-0.88	-0.45	-0.74	0.71	-0.18	1.40	-0.24
11	202.50 TO 222.50	-0.58	0.09	-1.01	0.05	-1.34	-0.81	-0.79	-0.98	0.81	-0.42	1.63	-0.70
12	222.50 TO 242.50	-1.13	0.51	-0.38	-0.03	-1.28	-0.34	-0.48	-0.44	0.82	-0.51	1.37	-1.21
13	242.50 TO 262.50	-0.91	-0.03	-1.51	0.08	-0.45	0.04	-0.46	0.02	0.75	0.07	0.49	-1.07
14	262.50 TO 282.50	0.60	0.27	0.15	-0.11	-0.12	0.31	-0.54	-0.57	0.51	-0.13	0.04	-0.51
15	282.50 TO 302.50	0.39	0.67	-3.12	0.18	-0.62	0.28	-0.47	-0.66	0.61	0.20	-0.03	-0.22
16	302.50 TO 322.50	-0.24	0.49	-1.75	-0.31	-1.22	-0.35	-1.34	-0.44	-0.24	-0.23	0.47	-0.81
17	322.50 TO 342.50	0.71	-0.66	-0.37	-0.04	-0.51	-0.49	-0.45	-0.15	0.27	-0.07	0.63	-0.67
18	342.50 TO 2.50	0.18	0.68	0.19	-0.25	-0.99	-0.77	-0.05	-0.10	0.57	-0.10	1.14	-0.14
19	CALM CONDITIONS*												
	AVERAGE:	-0.36	0.18	-0.59	-0.13	-0.51	-0.52	-0.58	-0.29	0.32	-0.02	0.91	-0.48

* The 19th bin (calm conditions) corresponds to NWS wind speeds of less than 1.1 m/s, for which the NWS wind direction is indeterminate.

TABLE 3-4. (Continued)

(c) Wind direction regression intercepts

BIN NO.	WIND DIRECTION	ABC	ABF	ABH	BAM	CON	FIR	FLA	HUN	KEN	ODT	SUN	WOR
1	2.50 TO 22.50	-25.	-29.	-6.	-7.	-21.	-11	-18.	6.	-11.	0	21.	-28.
2	22.50 TO 42.50	-27.	-11.	-40.	-4	-16.	-12.	-13.	9.	-10.	-5.	16.	-26.
3	42.50 TO 62.50	-19.	-47.	-31	-5	-21.	-13	-9.	-2.	-6.	-8.	15.	-17.
4	62.50 TO 82.50	-9.	-68.	-9.	-5	-12	5	-1.	-9.	-6.	-9.	17.	-15.
5	82.50 TO 102.50	17.	-104	3	-2.	-4.	15.	-15.	-20.	-3	-10.	25.	-14.
6	102.50 TO 122.50	40.	4	2	-5	1.	36	-19.	-37.	4.	-24	23.	-20.
7	122.50 TO 142.50	25.	13.	-0.	2.	-13.	17.	-16	-46.	5.	-36	27.	-24.
8	142.50 TO 162.50	12.	44.	-18.	-0	-23.	4	-8.	-48	-1	-35.	38.	-37.
9	162.50 TO 182.50	4.	34.	-30.	1	-29.	-5.	-20	-42.	2.	-37.	12.	-46.
10	182.50 TO 202.50	-0.	21	-28.	5	-23.	-9.	-29	-19.	3.	-39.	26	-42.
11	202.50 TO 222.50	-9.	17.	-31.	1.	-32.	-18.	-32.	-6	-1	-40.	19.	-44.
12	222.50 TO 242.50	-17.	5.	-9.	3.	-21.	-29.	-10	11.	-6.	-12.	20.	-24.
13	242.50 TO 262.50	-13	1	8.	5.	-18.	-29.	11.	6.	-4.	12.	9.	-11.
14	262.50 TO 282.50	-19.	-3	8	4	-11.	-10.	4	3	-9.	10.	3.	-11.
15	282.50 TO 302.50	-19.	8	-0.	-5.	-6.	7.	11.	-1.	-13	21.	8.	-4.
16	302.50 TO 322.50	-17.	40	-22.	-3.	-8	19.	5.	2.	-13	9	4.	-13.
17	322.50 TO 342.50	-20.	-13.	-24	-12.	-18	8.	-6	-5	-18	2	5.	-23.
18	342.50 TO 7.50	-36.	-18.	-41	-18.	-23	-10.	-12	10	-17.	-1.	5.	-33.
19	CALM CONDITIONS*												
	AVERAGE	-7.	-5.	-15.	-2	-17.	-2.	-10	-10.	-6.	-11.	16.	-24.

* The 19th bin (calm conditions) corresponds to NWS wind speeds of less than 1.1 m/s, for which the NWS wind direction is indeterminate.

TABLE 3-4. (Continued)

(d) Interquartile range of wind speed residuals

BIN NO.	WIND DIRECTION	ABC	ABF	ASH	BAM	CON	FIR	FLA	HUN	KEN	ODT	SUN	WOR
1	2.50 TO 22.50	1.02	1.00	1.16	0.70	1.05	1.14	0.81	0.68	1.03	0.94	0.99	1.21
2	22.50 TO 42.50	0.77	1.40	0.94	0.83	1.08	1.11	0.83	0.56	1.10	0.94	1.03	1.36
3	42.50 TO 62.50	1.02	0.78	0.95	0.74	0.87	0.83	0.75	0.54	1.14	1.08	1.54	1.32
4	62.50 TO 82.50	0.88	0.76	1.21	0.66	0.85	0.81	0.85	0.54	1.05	0.79	1.42	1.29
5	82.50 TO 102.50	0.74	0.71	0.84	0.69	0.81	0.75	0.78	0.45	1.19	0.67	1.44	1.19
6	102.50 TO 122.50	0.69	0.85	1.08	0.72	0.97	0.89	0.75	0.51	1.16	0.83	1.53	1.24
7	122.50 TO 142.50	0.75	0.73	1.24	0.70	0.97	0.94	1.06	0.54	1.14	0.84	1.14	1.12
8	142.50 TO 162.50	0.78	1.05	1.44	0.64	1.12	1.00	1.07	0.89	1.27	0.89	1.93	1.25
9	162.50 TO 182.50	0.80	1.66	1.31	0.69	1.07	1.01	1.16	0.96	1.20	1.17	1.87	1.08
10	182.50 TO 202.50	1.09	1.75	0.84	0.58	0.95	0.98	1.09	1.18	1.30	1.03	1.41	1.10
11	202.50 TO 222.50	1.57	1.37	0.95	0.67	1.43	0.94	1.12	1.19	1.30	1.17	1.69	1.35
12	222.50 TO 242.50	1.82	1.04	1.00	0.73	1.41	1.01	1.34	1.06	1.21	1.24	1.72	1.54
13	242.50 TO 262.50	1.65	1.39	1.10	0.86	1.23	0.84	1.47	0.94	1.10	1.11	1.66	1.70
14	262.50 TO 282.50	1.41	1.33	1.35	0.93	1.69	0.56	1.74	1.06	1.25	1.34	1.82	1.73
15	282.50 TO 302.50	1.04	1.29	2.42	0.97	1.56	1.09	1.42	0.97	1.27	1.18	1.57	1.51
16	302.50 TO 322.50	1.35	1.61	1.62	0.83	1.17	1.37	1.52	1.02	1.24	1.11	1.35	1.60
17	322.50 TO 342.50	1.35	0.91	1.26	0.87	1.32	1.08	1.47	0.81	1.04	1.16	1.31	1.38
18	342.50 TO 2.50	1.07	0.85	1.16	0.75	1.36	1.07	1.04	0.78	0.99	0.95	1.42	1.23
19	CALM CONDITIONS*												
	AVERAGE:	1.10	1.14	1.21	0.75	1.16	0.97	1.13	0.82	1.17	1.02	1.49	1.34

* The 19th bin (calm conditions) corresponds to NWS wind speeds of less than 1.1 m/s, for which the NWS wind direction is indeterminate.

TABLE 3-4. (Continued)

(e) Interquartile range of wind direction residuals

BIN NO.	WIND DIRECTION	ABC	ABF	ASH	BAM	CON	FIR	FLA	HUN	KEN	ODT	BUN	WOR
1	2.50 TO 22.50	66.	33.	109	48.	49.	33.	55.	47.	40.	51.	44.	86.
2	22.50 TO 42.50	79.	51.	83.	54.	48.	55.	67.	39.	42.	53.	54.	91.
3	42.50 TO 62.50	54.	58.	105.	32.	49.	64.	48.	36.	37.	41.	46.	60.
4	62.50 TO 82.50	32.	80.	96.	25.	50.	99.	62.	33.	35.	30.	37.	51.
5	82.50 TO 102.50	94.	81.	46.	49.	53.	116.	50.	30.	40.	32.	44.	38.
6	102.50 TO 122.50	88.	277.	15.	58.	24.	58.	37.	31.	35.	33.	36.	29.
7	122.50 TO 142.50	75.	208.	11.	54.	27.	52.	47.	44.	48.	43.	51.	40.
8	142.50 TO 162.50	54.	125.	18.	47.	31.	39.	43.	84.	44.	67.	62.	45.
9	162.50 TO 182.50	46.	92.	32.	42.	41.	39.	40.	114.	37.	85.	41.	73.
10	182.50 TO 202.50	35.	25.	56.	49.	58.	42.	63.	104.	30.	104.	46.	94.
11	202.50 TO 222.50	27.	33.	94.	36.	68.	37.	88.	80.	24.	110.	41.	127.
12	222.50 TO 242.50	26.	46.	62.	33.	58.	38.	72.	52.	28.	64.	39.	69.
13	242.50 TO 262.50	31.	35.	30.	27.	36.	72.	49.	30.	25.	26.	32.	33.
14	262.50 TO 282.50	31.	26.	21.	25.	35.	139.	41.	17.	25.	35.	30.	36.
15	282.50 TO 302.50	31.	51.	20.	28.	32.	82.	30.	30.	27.	39.	39.	35.
16	302.50 TO 322.50	36.	122.	23.	25.	23.	19.	18.	43.	22.	24.	42.	40.
17	322.50 TO 342.50	37.	43.	33.	19.	24.	15.	27.	34.	25.	31.	41.	43.
18	342.50 TO 2.50	44.	33.	33.	18.	34.	24.	38.	69.	26.	38.	36.	39.
19	CALM CONDITIONS*												
	AVERAGE:	49.	79.	49.	37.	41.	57.	49.	51.	33.	50.	42.	58.

* The 19th bin (calm conditions) corresponds to NWS wind speeds of less than 1.1 m/s, for which the NWS wind direction is indeterminate.

TABLE 3-4. (Continued)

(f) Average over stations of interquartile range

BIN NO.	WIND DIRECTION			SPEED	DIRECTION
1--------	2.50	TO	22.50	0.90	51.
2-------	22.50	TO	42.50	0.92	55.
3-------	42.50	TO	62.50	0.89	48.
4-------	62.50	TO	82.50	0.85	48.
5-------	82.50	TO	102.50	0.79	52.
6------	102.50	TO	122.50	0.86	55.
7------	122.50	TO	142.50	0.86	54.
8------	142.50	TO	162.50	1.03	51.
9------	162.50	TO	182.50	1.08	52.
10------	182.50	TO	202.50	1.02	54.
11------	202.50	TO	222.50	1.13	59.
12------	222.50	TO	242.50	1.16	45.
13------	242.50	TO	262.50	1.16	33.
14------	262.50	TO	282.50	1.25	35.
15------	282.50	TO	302.50	1.25	34.
16------	302.50	TO	322.50	1.22	34.
17------	322.50	TO	342.50	1.07	29.
18------	342.50	TO	2.50	0.97	35.
19------	CALM CONDITIONS*				
	GLOBAL AVERAGE:			1.02	46.

* The 19th bin (calm conditions) corresponds to NWS wind speeds of less than 1.1 m/s, for which the NWS wind direction is indeterminate.

TABLE 3-4. (Continued)

(g) Wind speed regression rms errors

BIN NO.	WIND DIRECTION	ABC	ABF	ASH	BAM	CON	FIR	FLA	HUN	KEN	ODT	SUN	WOR
1	----------2.50 TO 22.50	0.83	0.81	0.89	0.54	0.89	0.86	0.68	0.56	0.82	0.74	0.89	0.91
2	---------22.50 TO 42.50	0.77	1.01	0.84	0.35	0.77	0.77	0.73	0.43	0.81	0.68	0.98	0.98
3	---------42.50 TO 62.50	0.81	0.63	0.80	0.51	0.70	0.65	0.72	0.44	0.82	0.73	1.11	0.97
4	---------62.50 TO 82.50	0.76	0.56	0.85	0.47	0.76	0.59	0.64	0.42	0.75	0.64	1.04	1.06
5	---------82.50 TO 102.50	0.63	0.63	0.73	0.51	0.65	0.52	0.65	0.38	0.80	0.58	1.30	0.94
6	--------102.50 TO 122.50	0.52	0.68	0.94	0.56	0.83	0.61	0.61	0.45	0.78	0.63	1.08	0.92
7	--------122.50 TO 142.50	0.67	1.18	0.93	0.58	0.84	0.73	0.80	0.48	0.82	0.68	1.10	0.88
8	--------142.50 TO 162.50	0.73	1.07	0.91	0.54	1.14	0.76	0.81	0.60	0.84	0.81	1.22	0.98
9	--------162.50 TO 182.50	0.76	1.15	0.97	0.53	1.01	0.82	0.84	0.79	0.89	0.90	1.29	0.85
10	--------182.50 TO 202.50	1.10	1.09	0.71	0.43	1.15	0.74	0.76	0.85	0.92	0.80	1.00	1.03
11	--------202.50 TO 222.50	1.34	0.98	1.29	0.50	1.30	0.73	0.94	0.91	0.94	0.88	1.20	1.19
112	--------222.50 TO 242.50	1.53	1.03	0.86	0.60	1.38	0.71	1.22	0.79	0.94	1.02	1.22	1.33
13	--------242.50 TO 262.50	1.44	0.88	1.38	0.71	1.25	0.66	1.29	0.79	0.88	0.86	1.25	1.36
14	--------262.50 TO 282.50	1.36	1.02	1.04	0.77	1.55	0.62	1.51	0.83	0.99	1.02	1.26	1.44
15	--------282.50 TO 302.50	1.05	1.14	2.94	0.70	1.51	0.90	1.20	0.79	1.06	0.90	1.44	1.33
16	--------302.50 TO 322.50	1.12	1.13	1.25	0.70	1.41	1.04	1.21	0.78	1.05	0.86	1.15	1.20
17	--------322.50 TO 342.50	1.04	0.83	0.93	0.72	1.32	0.86	0.98	0.70	0.81	0.82	1.26	1.08
18	--------342.50 TO 2.50	0.83	0.61	0.98	0.60	1.18	0.77	0.87	0.60	0.80	0.72	1.08	1.03
19	--------CALM CONDITIONS*												
	AVERAGE:	0.96	0.91	1.08	0.58	1.09	0.74	0.92	0.64	0.87	0.79	1.16	1.08

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* The 19th bin (calm conditions) corresponds to NWS wind speeds of less than 1.1 m/s, for which the NWS wind direction is indeterminate.

TABLE 3-4. (Continued)

(h) Wind direction regression rms errors

BIN NO.	WIND DIRECTION	ABC	ASF	ASH	BAM	CON	FIR	FLA	HUN	KEN	ODT	SUN	WOR
1	2.50 TO 22.50	60.	35.	70.	51.	52	63.	44.	47	38.	48.	51.	63.
2	22.50 TO 42.50	62.	30.	69.	49.	53.	64.	56.	37.	41.	44.	58.	68.
3	42.50 TO 62.50	72	39.	71.	40.	48	75.	49.	33	43.	42.	49.	70.
4	62.50 TO 82.50	71.	50.	71.	36.	52	71.	55.	34	40.	37.	57.	77.
5	82.50 TO 102.50	70.	56.	72.	47.	50.	77.	55.	29.	47.	37.	53.	70.
6	102.50 TO 122.50	61.	131.	45.	43.	37.	61.	48.	32	39.	36.	50.	48.
7	122.50 TO 142.50	65.	129.	54.	55.	52.	65.	64.	48	57.	41.	51.	63.
8	142.50 TO 162.50	44.	92.	56.	46.	38	49.	64.	61	48.	44.	51.	56.
9	162.50 TO 182.50	43.	57.	36.	47.	41	50.	60.	68	43.	53.	36.	58.
10	182.50 TO 202.50	40.	45.	57.	47.	56.	53.	66.	78.	37.	66.	32.	66.
11	202.50 TO 222.50	32.	49.	63.	35.	56.	60.	68.	76.	24.	67.	35.	74.
12	222.50 TO 242.50	27.	40.	64.	35.	50.	61.	69.	56.	30.	69.	34.	74.
13	242.50 TO 262.50	32	52.	36.	25.	41.	65.	49.	37.	29.	42.	29.	49.
14	262.50 TO 282.50	29.	46.	35.	29.	47.	72.	58.	35.	26.	45.	32.	45.
15	282.50 TO 302.50	34.	81.	33.	39.	51.	66.	45.	39.	30.	50.	40.	53.
16	302.50 TO 322.50	39.	65.	31.	33.	34.	39.	37.	43.	27.	34.	44.	43.
17	322.50 TO 342.50	38.	49.	38.	32.	41.	37.	32.	38.	29.	35.	35.	44.
18	342.50 TO 2.50	43.	37.	29.	31.	35.	48.	40.	52.	29.	37.	46.	50.
19	CALM CONDITIONS*												
	AVERAGE:	48.	60.	52.	40.	46.	60.	53.	47.	36.	46.	44.	59.

* The 19th bin (calm conditions) corresponds to NWS wind speeds of less than 1.1 m/s, for which the NWS wind direction is indeterminate.

TABLE 3-4. (Concluded)

(i) Wind speed means

BIN NO.	WIND DIRECTION	ABC	ASF	ASH	BAM	CON	FIR	FLA	HUN	KEN	ODT	SUN	WOR
1	2.50 TO 22.50	1.66	1.82	1.74	1.07	1.76	1.50	1.42	1.27	2.31	1.83	2.32	1.80
2	22.50 TO 42.50	1.63	2.34	2.00	1.14	1.66	1.31	1.31	1.25	2.34	1.65	2.30	1.92
3	42.50 TO 62.50	1.80	1.68	1.65	1.36	1.64	1.06	1.49	1.35	2.45	1.77	2.66	2.04
4	62.50 TO 82.50	1.59	1.57	1.65	1.38	1.60	0.96	1.22	1.33	2.33	1.56	2.55	1.81
5	82.50 TO 102.50	1.44	1.25	1.42	1.26	1.34	0.70	1.16	1.18	2.13	1.45	2.73	1.86
6	102.50 TO 122.50	1.10	1.26	2.30	1.17	1.67	0.72	1.01	1.05	2.07	1.41	3.23	1.68
7	122.50 TO 142.50	1.28	1.40	2.08	1.15	1.90	1.00	1.32	1.02	2.12	1.54	3.12	1.61
8	142.50 TO 162.50	1.61	2.32	2.54	1.36	2.31	1.41	1.65	1.34	2.17	1.97	3.42	1.87
9	162.50 TO 182.50	1.72	3.11	2.92	1.37	2.40	1.40	1.67	1.51	2.59	2.05	3.82	1.68
10	182.50 TO 202.50	1.98	2.97	2.28	1.21	2.35	1.09	1.47	1.50	2.63	2.01	3.20	1.73
11	202.50 TO 222.50	2.27	2.66	1.89	1.32	2.50	0.95	1.47	1.58	2.91	2.00	3.43	1.97
12	222.50 TO 242.50	3.13	2.36	2.04	1.53	2.99	1.04	2.11	2.05	2.99	2.40	3.43	2.51
13	242.50 TO 262.50	3.35	2.69	2.81	2.10	3.62	0.92	2.88	2.51	3.34	2.96	3.95	3.39
14	262.50 TO 282.50	3.17	2.88	3.19	2.41	3.65	0.72	3.24	2.99	3.67	2.99	4.34	3.64
15	282.50 TO 302.50	2.93	3.07	4.61	2.39	3.57	1.08	3.39	2.68	3.89	2.93	4.01	3.69
16	302.50 TO 322.50	2.75	2.81	4.11	2.19	3.42	1.78	3.34	2.21	3.84	2.84	3.56	3.21
17	322.50 TO 342.50	2.63	2.54	3.37	1.90	2.96	1.98	2.49	2.01	3.26	2.49	3.50	2.08
18	342.50 TO 2.50	1.93	2.25	2.81	1.45	2.49	1.67	1.79	1.45	2.62	2.08	2.47	2.10
19	CALM CONDITIONS*												
	AVERAGE:	2.11	2.28	2.52	1.54	2.43	1.18	1.91	1.68	2.76	2.11	3.22	2.30

* The 19th bin (calm conditions) corresponds to NWS wind speeds of less than 1.1 m/s, for which the NWS wind direction is indeterminate.

TABLE 3-5. REGRESSION STATISTICS FOR
CALM NWS WINDS (BIN 19).

	u		v	
Station	Mean	RMS Error	Mean	RMS Error
ABC	-0.28	0.62	-0.52	0.67
ASF	-0.17	0.64	-0.79	0.63
ASH	-0.25	0.61	0.47	0.77
BAM	0.0	0.39	0.04	0.39
CON	0.0	0.59	0.10	0.87
FIR	-0.09	0.31	0.01	0.22
FLA	0.09	0.38	0.05	0.48
HUN	0.04	0.35	0.42	0.42
KEN	-0.06	1.19	-0.12	0.85
ODT	0.43	0.41	0.81	0.59
SUN	-0.44	1.46	-0.13	1.52
WOR	0.0	0.57	0.08	0.86

bin 5 to bin 6 (Figures, pages 115 and 116). Appaarently, so much scatter exists in the ASF wind directions in these bins that the mean direction is not physically well defined (Figures, pages 82 and 83). This scatter of directions is not surprising given the slow average wind speeds at ASF in these two bins (1.24 m/s average over those times that the NWS wind speed is greater than 1.1 m/s). The large values of the interquartile range of wind direction residuals, which indicate an unreliable predictor of direction in these bins, directly reflect this scatter (Table, page 99).

High interquartile ranges at FIR in a few bins are due to low wind speeds. Of the 12 stations, FIR has the slowest average wind speeds (using only those times during which the NWS wind speed is greater than 1.1 m/s, FIR has an average speed of 1.2 m/s) (see Appendix D). FIR has its highest interquartile ranges and also its slowest wind speeds in bins 5 and 14 (Appendix D), with calm winds of 76 percent and 79 percent, respectively, in these directions, which are 180° apart. Examination of the sequence of wind roses (Figures, pages 90, 91, and 92) and the scatter plot [Figure B-1, pages 53-76] shows that westerly winds are not observed at this station, indicating that there may be an obstruction to the west of FIR. This obstruction would cause the large fluctuations in wind direction at FIR since bins 5 and 14 correspond to easterly and westerly winds at the NWS station.

At the FLA station, the high interquartile ranges for wind direction are associated with low wind speeds in those directions, with the exception of bin 13 (242° to 262°; Table, page 104). Bin 12 does not have a slow average wind speed, but experiences a significant amount of calm winds (33 percent). At FLA, bin 13 shows the effect of the channeling of the wind field by the valley at some times and not at others (Figure, page 90), resulting in the large interquartile range (49°).

HUN also exhibits valley channeling of the flow. In bin 7, we see a significant shift in wind direction due to channeling. Bins 8 and 9 exhibit a transitional phase between channeling and no channeling (Bin 10) and experience the greatest fluctuation in wind direction at HUN, as indicated by the interquartile range (Table, page 105). Bins 9 and 10 have the highest interquartile ranges for the direction residuals at HUN. NWS wind directions (southerly wind; 162° to 202°) defining these bins are transverse to the valley; therefore, both these high ranges and the high percent of calm (50 percent) in these directions are probably due to the steep terrain gradient just south of HUN, and perhaps also to the fact that HUN is in the lee of the town of Huntington.

In the preceding section, we have seen that slow wind speeds contribute significantly to cases of poor wind direction regression results. In general, the wind speeds are lowest when the winds are from the ESE and highest when the winds are from the WNW. In Figure 3-2, the average wind speeds at station ABC for each bin are plotted against the corresponding interquartile ranges for the wind direction residuals. These data are taken from Tables 3-4 (e) and (i). The curve (piecewise-linear) that seems to best fit the data has been drawn on these plots. This illustrates that at station ABC, the fluctuations in wind direction rapidly increase as the average wind speed falls below 2 m/s, whereas for speeds above 2 m/s, the interquartile range is small.

Another factor that detracts from the accuracy of the diagnosis concerns differences in the types of data obtained from the NWS station and from the other 12 network stations. Two differences exist: First, the NWS station wind speeds are reported every knot, and with wind directions reported every 10 degrees, whereas the network station values have a much higher resolution. Second, the NWS measurements are 1 minute averages taken once an hour, whereas data are collected every two minutes at the 12 network stations, and are averaged to produce the hourly values. The NWS data from adjacent hours are then averaged to obtain a better estimate of an hourly average.

The first of these differences will probably not bias the predictions since we expect a cancellation of the errors; however, this will increase the RMS goodness of fit measures because they depend on the squares of the errors and there is no cancellation.

The second difference between the two sets of data is more significant and can lead to poor results if the NWS data do not reflect hourly averages as is bound to occur for some hours. Again, there may be some cancellation of the errors induced in this manner as long as the NWS measurements are not significantly biased with respect to the true hourly averages. Thus, some

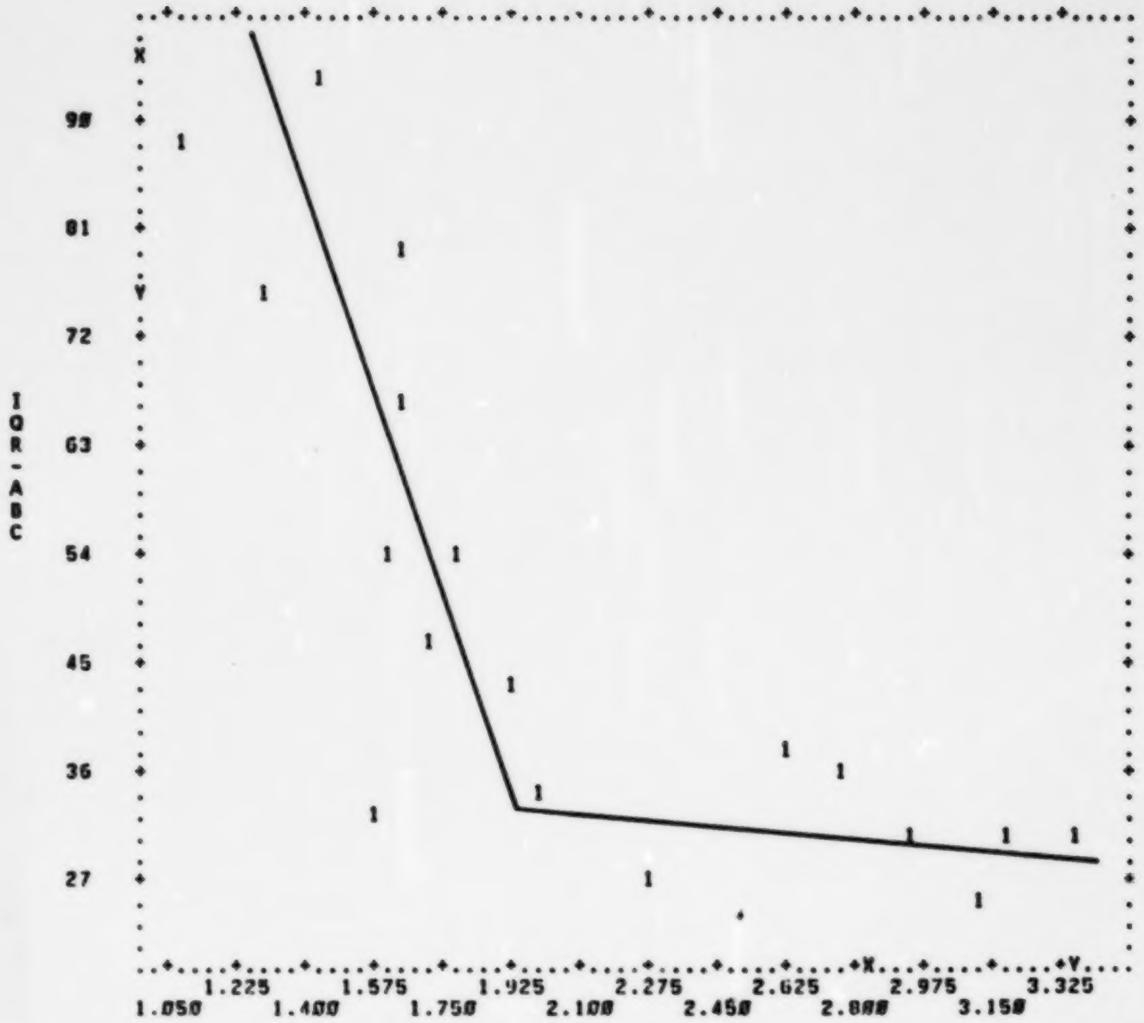

Figure 3-2. Station ABC, average wind speed vs. wind direction interquartile range for each NWS wind direction bin.

part of the wind direction fluctuations in the wind roses for each bin is due to incorrect hourly average values at the NWS station that cause data to be put into incorrect direction bins.

THE ENHANCED ACCURACY OF STATION PREDICTIONS OBTAINED FROM STRATIFICATION BY NWS WIND DIRECTION

The results presented in this section and in Appendices C through E show how station wind speed and direction change with the NWS wind direction bin. As explained earlier, the use of bins was motivated by a desire to allow for possible nonlinear relationships between station wind vectors and NWS wind vectors. We now consider the question of whether results indicate that this stratification was either necessary or useful in predicting station variables. The question may be addressed by testing two statistical hypotheses:

(1) That there is one underlying linear relation between station wind speeds and NWS wind speeds and, therefore, that the underlying regression coefficients are identical from one bin to the next.

(2) That there is one underlying wind direction parameter per station, again with no difference from one bin to the next, that can be used to predict station wind directions using the NWS wind direction.

These hypotheses were tested and rejected through analysis of variance and covariance methods.

Program BMDP7D (Dixon et al., 1981) was used to test for equality of station-to-NWS directional shift, parameters across NWS wind direction bins. The F statistics, (Scheffe, 1959) with numerator and denominator degrees of freedom equal to 17 and 3809, respectively, rejecting this global linear model, ranged from 5.68 at station BAM to 50.66 at station ODT. The corresponding tail probabilities (the so-called p-values) i.e., the probabilities of such large F statistics occurring by chance were there no underlying difference between bins, were all less than 0.00005. Thus, the bins are statistically highly significant in reducing the residual variance from that associated with a global linear model.

Note, however, that with the large sample sizes at hand, it is possible to detect bin differences that are statistically highly significant, yet that are not of large magnitude. For example, the use of one global wind direction shift parameter for station ABC results in a residual standard deviation of approximately 51°, and this is reduced to approximately 58° when shift parameters for each bin are used. Also, the use of analysis of variance (ANOVA) and other standard statistical methods must be viewed with some caution, when applied to directional data, since the usual Euclidean distance can be inappropriate for points on a circle. Nevertheless, the directional differences that were analyzed clustered near 0°; therefore, the ANOVA results appear to be valid.

A similar analysis was conducted to test for the presence of a bin effect in the wind speed regressions. Again, the statistical evidence against the hypothesis that a global linear relation exists between station wind speeds and the NWS wind speeds was highly significant, through the differences in residual standard deviations with and without the use of bins was small. For example, the residual standard deviation for station ABC was 1.16 m/s for the global linear regression and 1.08 m/s for bin-specific linear regressions.

SECTION 4

SUMMARY

The use of NWS surface wind speed and direction significantly improves the accuracy of the station surface wind descriptions when compared with use of the average wind field as the estimator. This is evident from the correlations between NWS and network wind speeds, which are typically near 0.7. Detailed results are presented in the appendices and are discussed in Section 3. It remains to be determined, however, whether the improvement in accuracy is sufficient for the estimated wind field to serve in a human exposure study, as an acceptable surrogate for the actual, but unknown, wind field during those years prior to 1980. In addition, we have by no means exhausted the possibilities for estimating the network wind field using NWS data. We conclude with a brief discussion of some refinements to the prediction methodology that appear to merit further investigation. Details concerning these refinements are given in Appendix F and are summarized below.

The following procedures may provide substantial and statistically significant improvements in the accuracy of wind field predictions:

Dynamic Wind Modeling

> Introduction of a dynamic wind model to spatially extrapolate the NWS wind measurement.

Refinement of Statistical Analysis

> Stratification of the data, on the basis of season, time of day, and stability class.

> Formulation of the predictive model in complex variables so that wind velocity can be represented by a single variable.

> Extension of the linear predictive model to include NWS measurements before and after the time of prediction (i.e., predict using a linear time series model).

> Use of principal component analysis to constrain the covariance matrix of the predicted wind field to conform more closely to that of the observed wind field.

> Use of cross-validation techniques to obtain better estimates of the likely predictive error.

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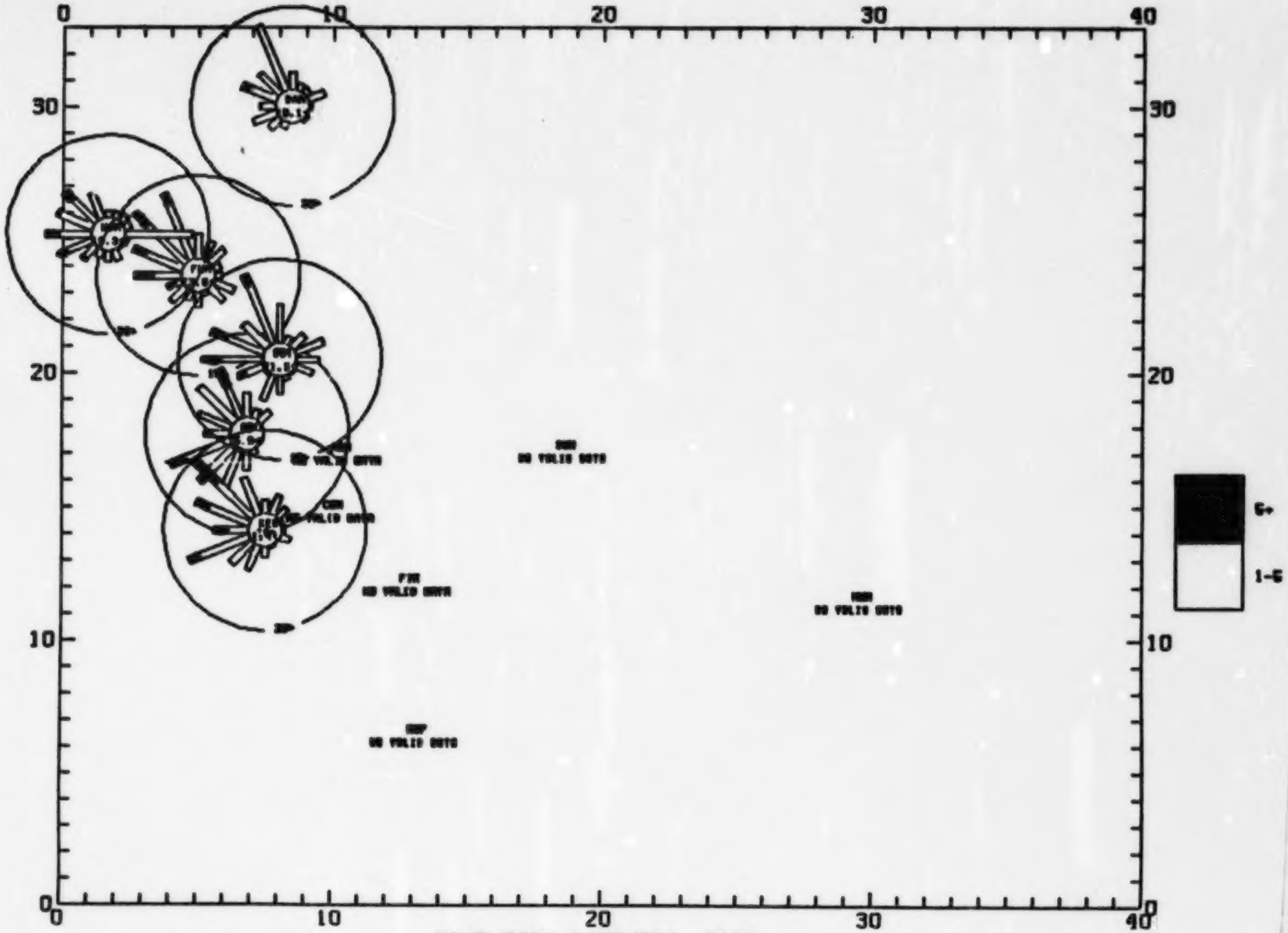
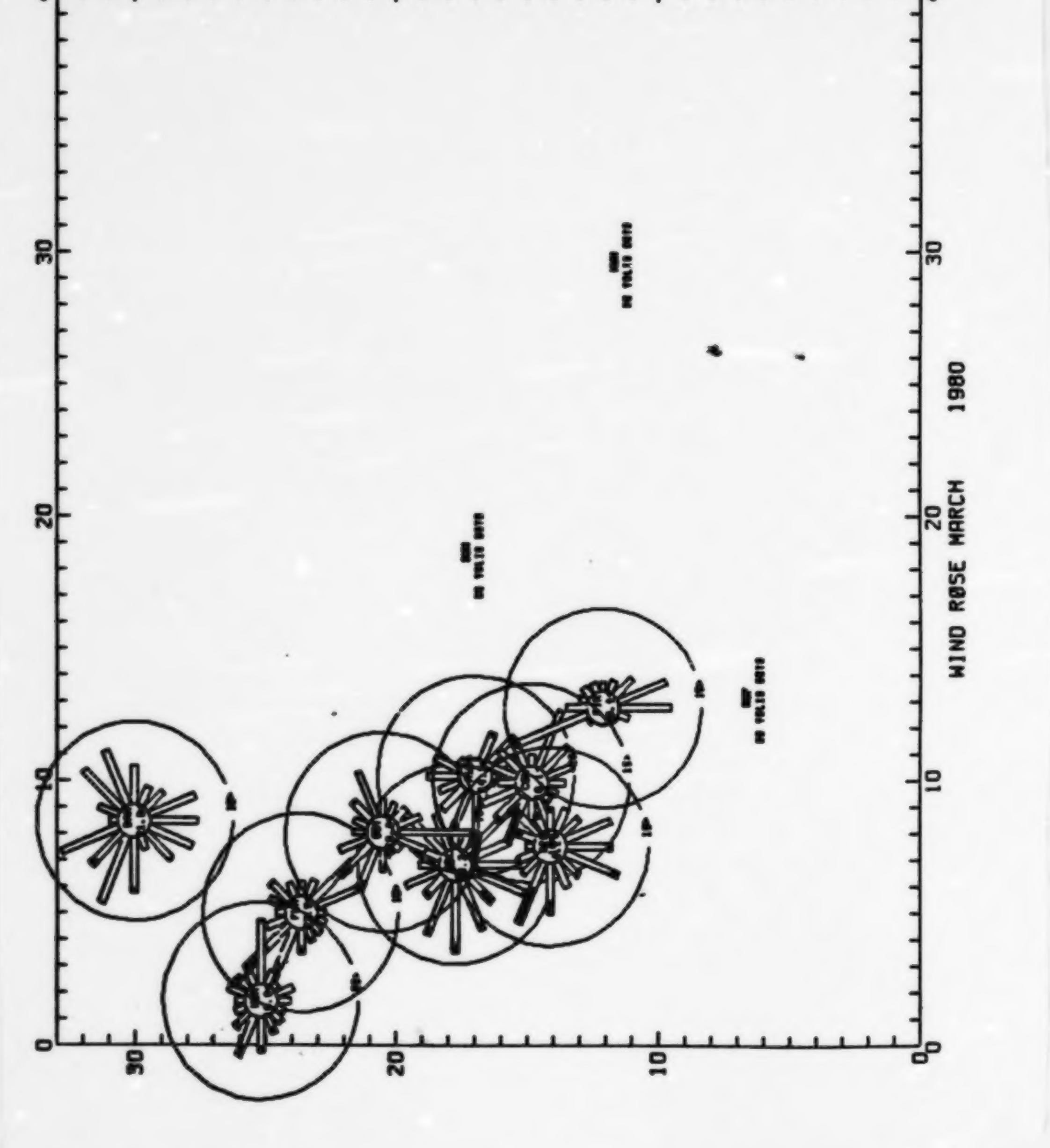
APPENDIX A

DISTRIBUTIONS OF WIND SPEEDS AND DIRECTIONS IN THE SOUTHEAST OHIO RIVER VALLEY

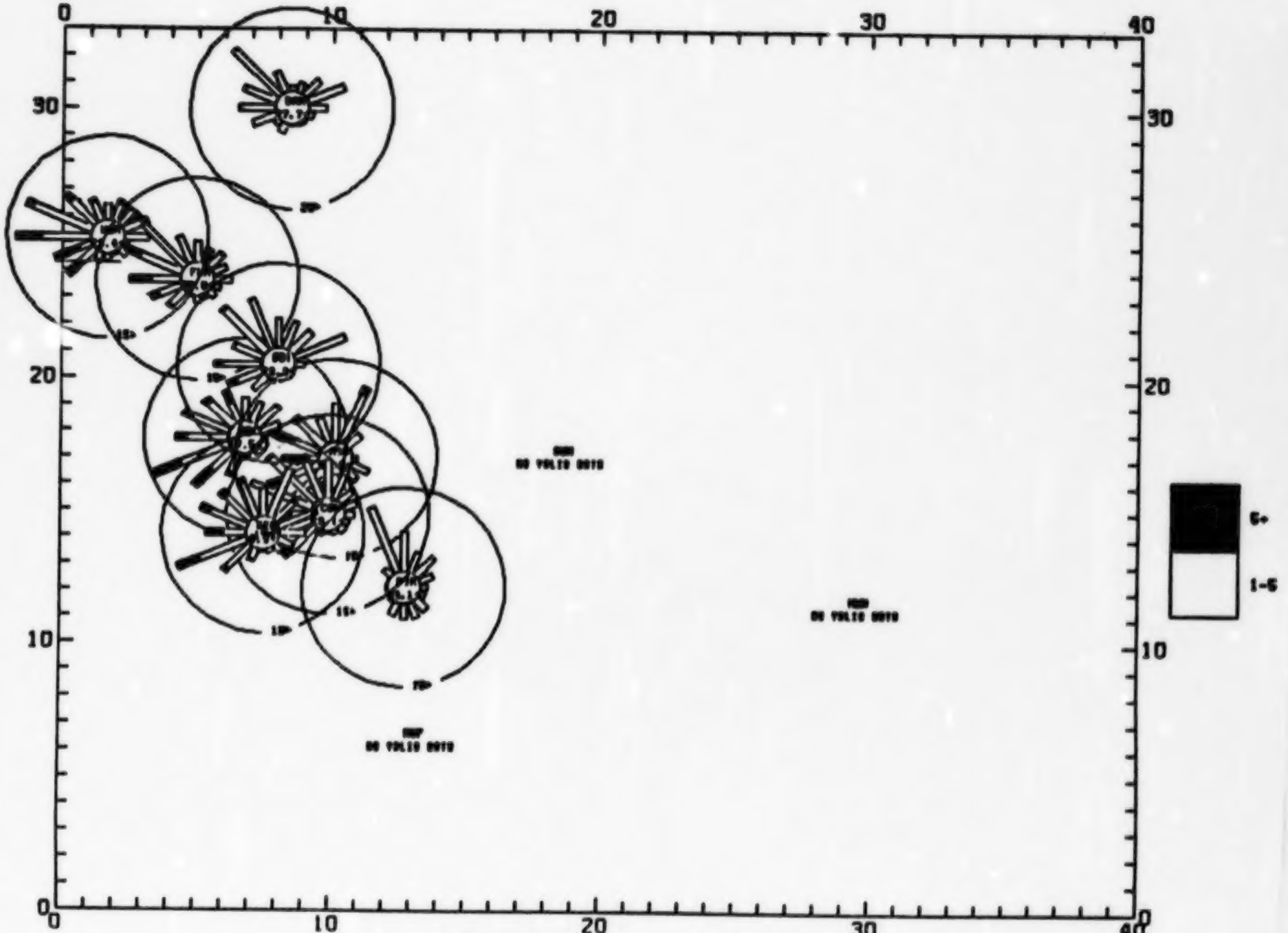


WIND RØSE FEBRUARY 1980

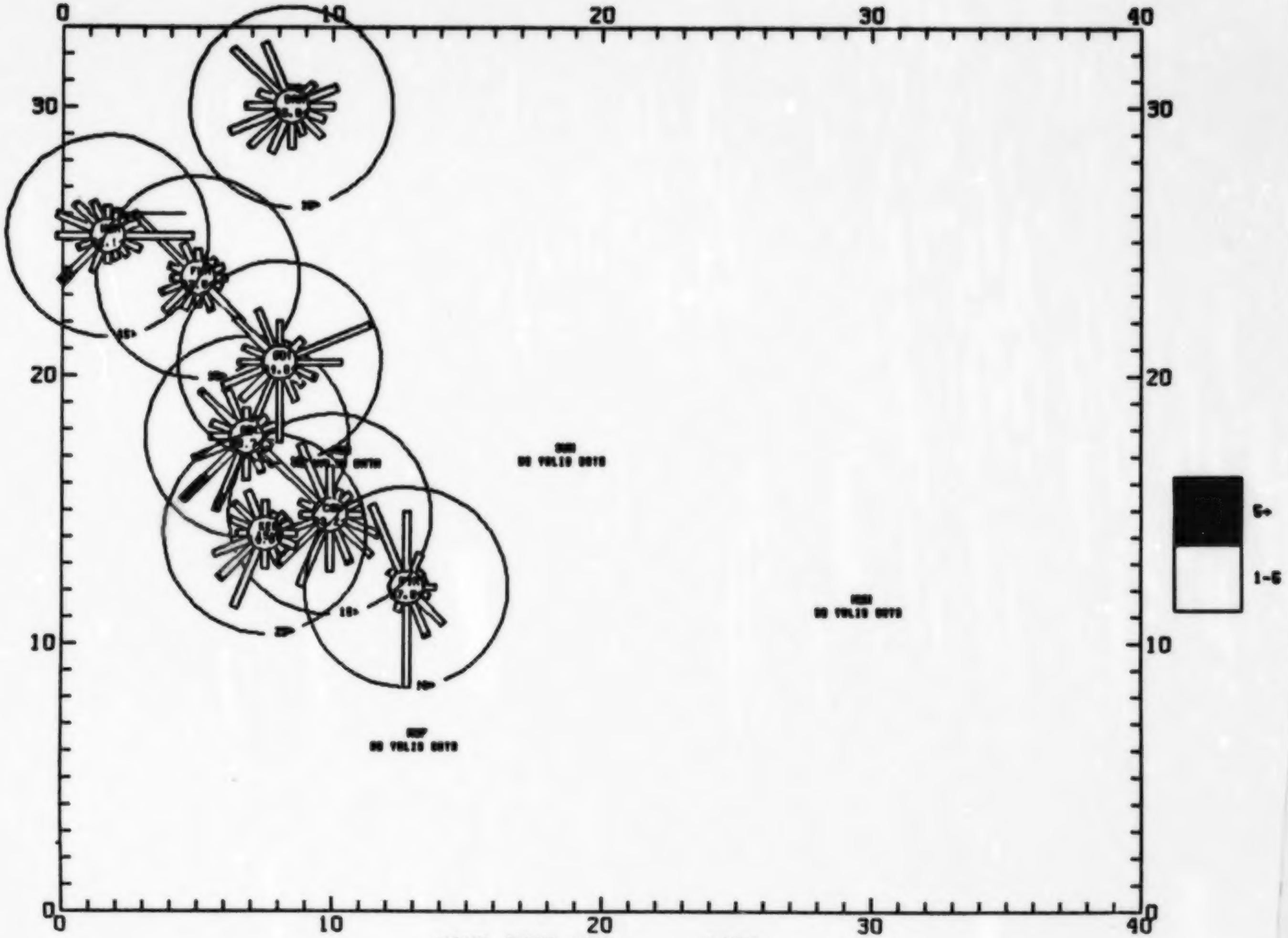
Reproduced from
best available copy.



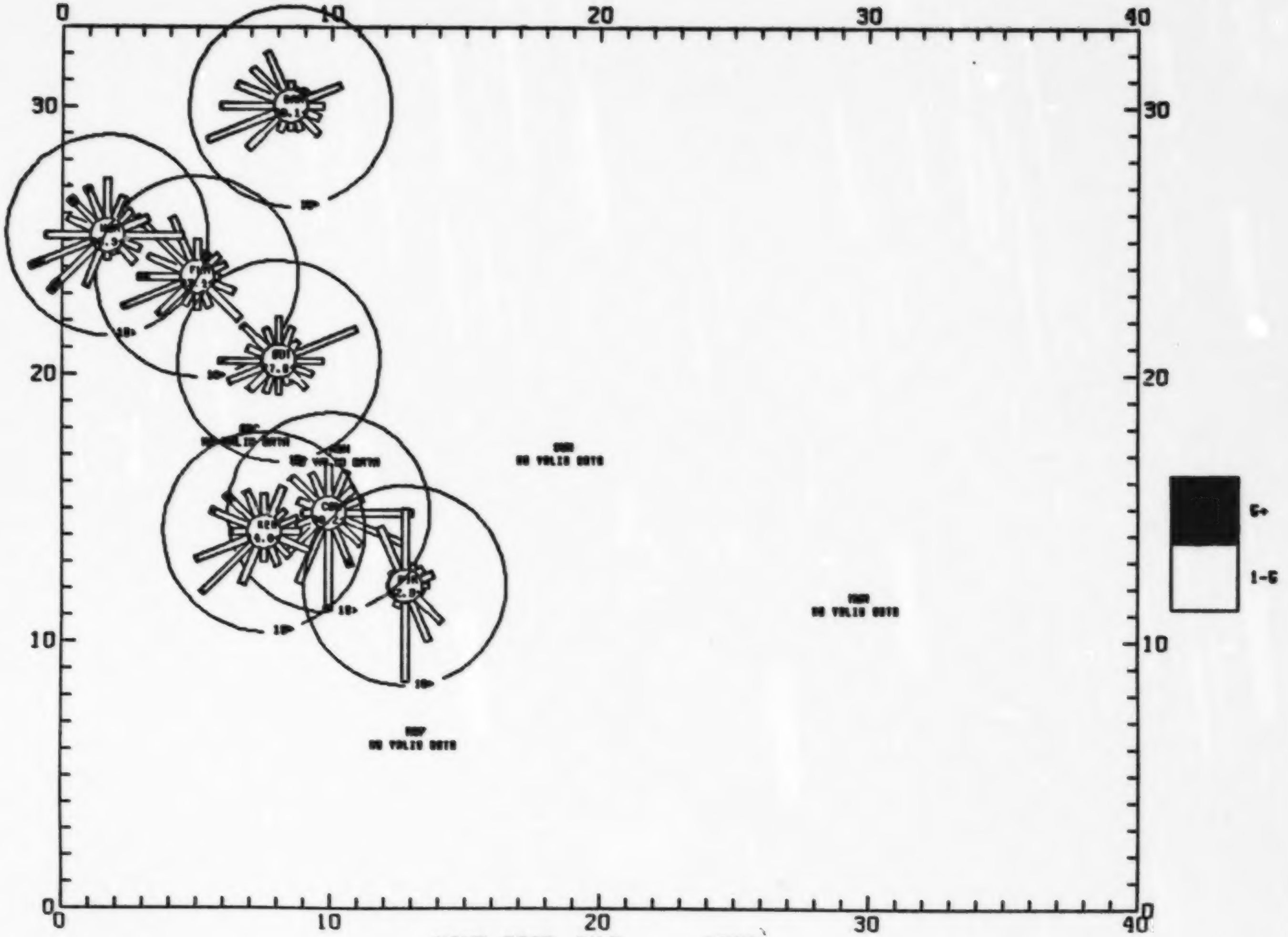
WIND ROSE MARCH 1980



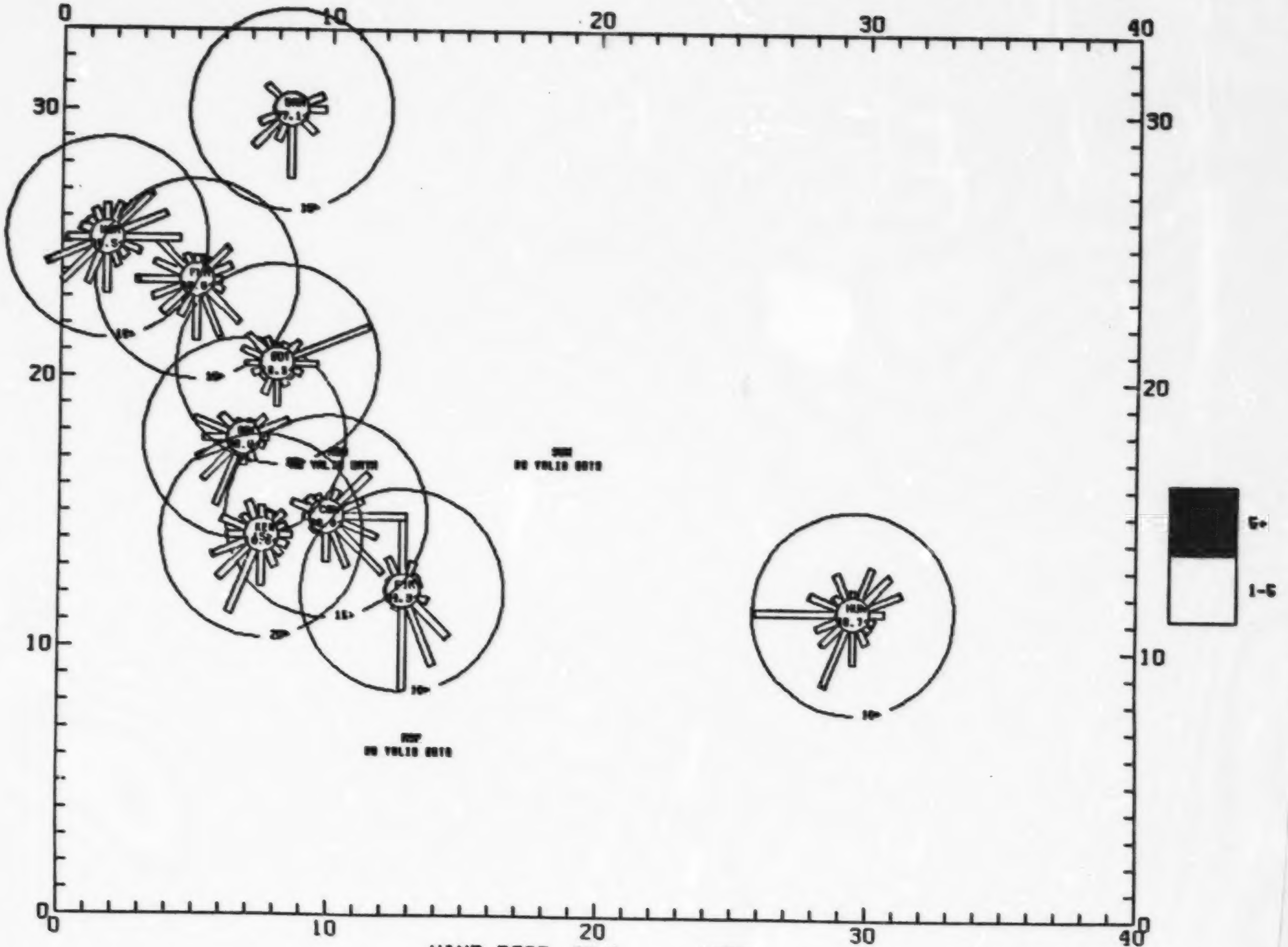
WIND RØSE APRIL 1980



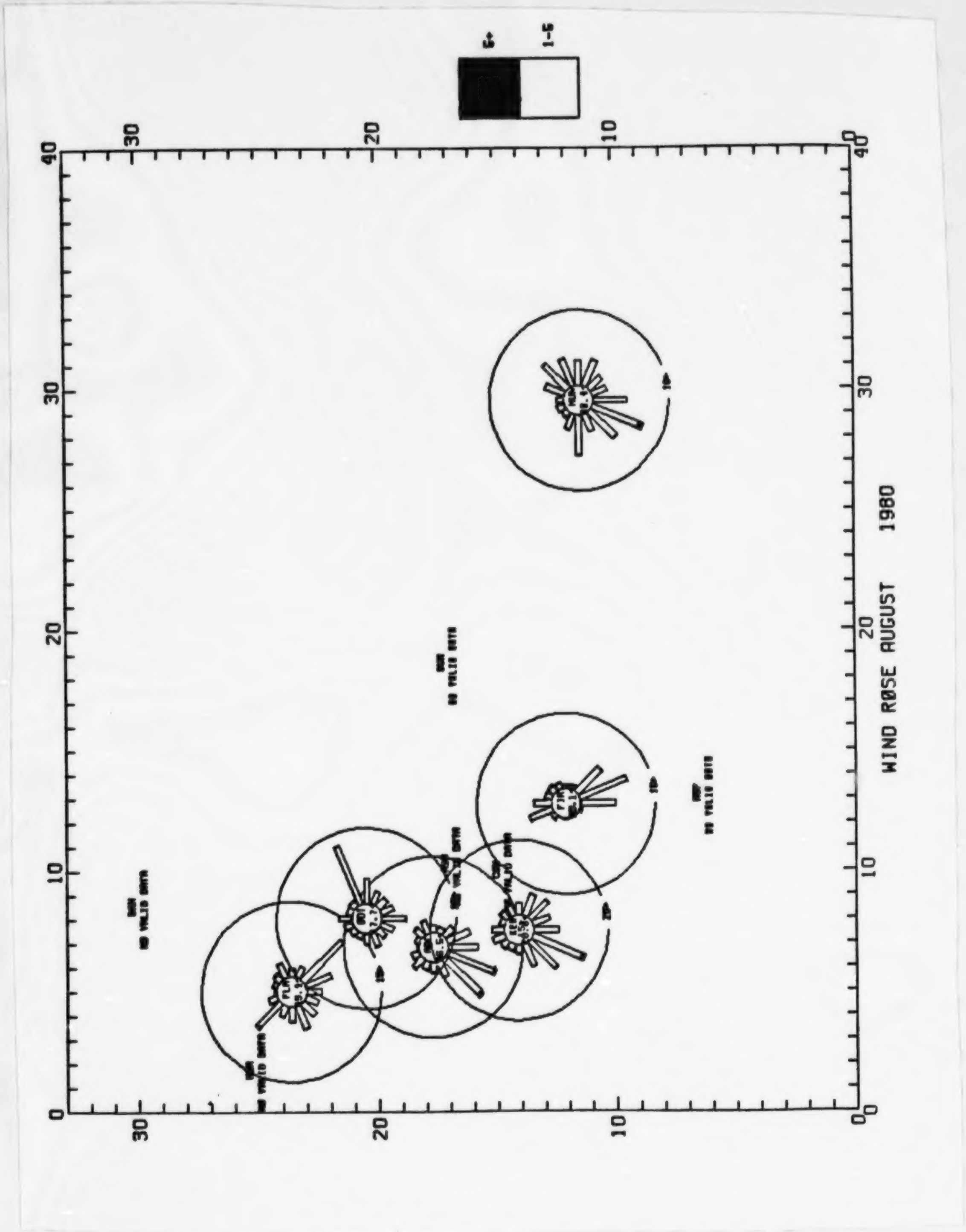
WIND RØSE MAY 1980

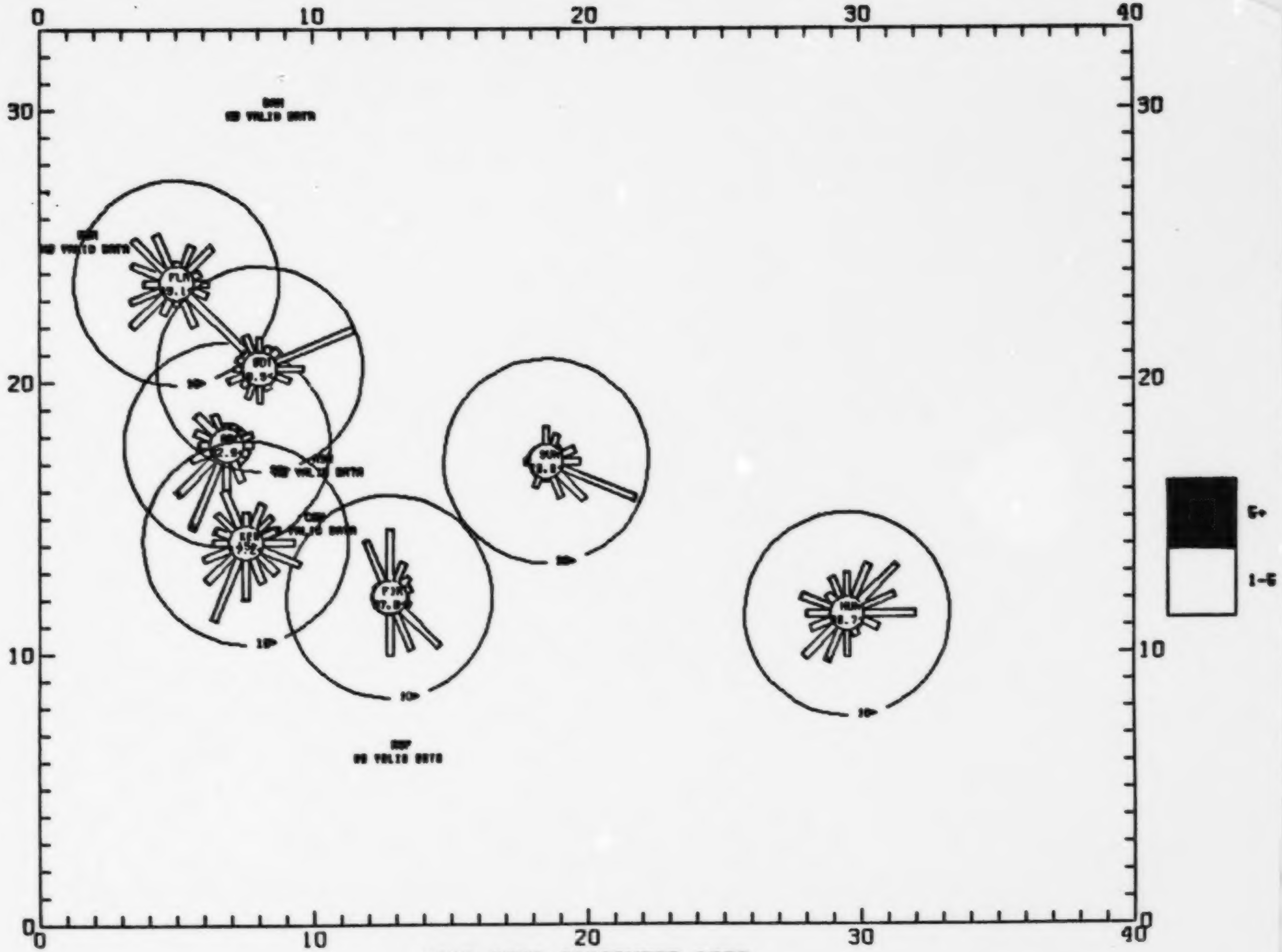


WIND RØSE JUNE 1980

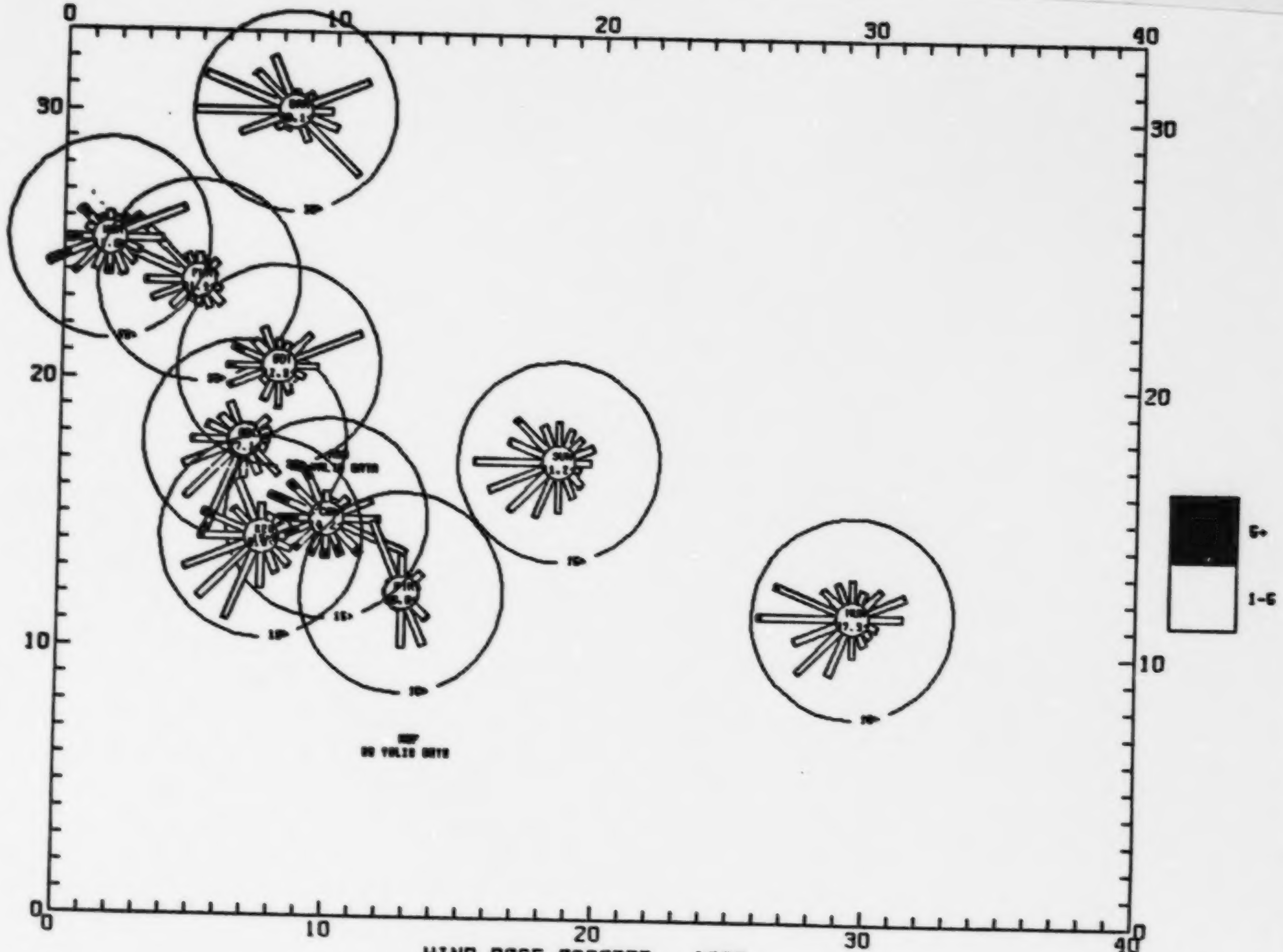


WIND RØSE JULY 1980

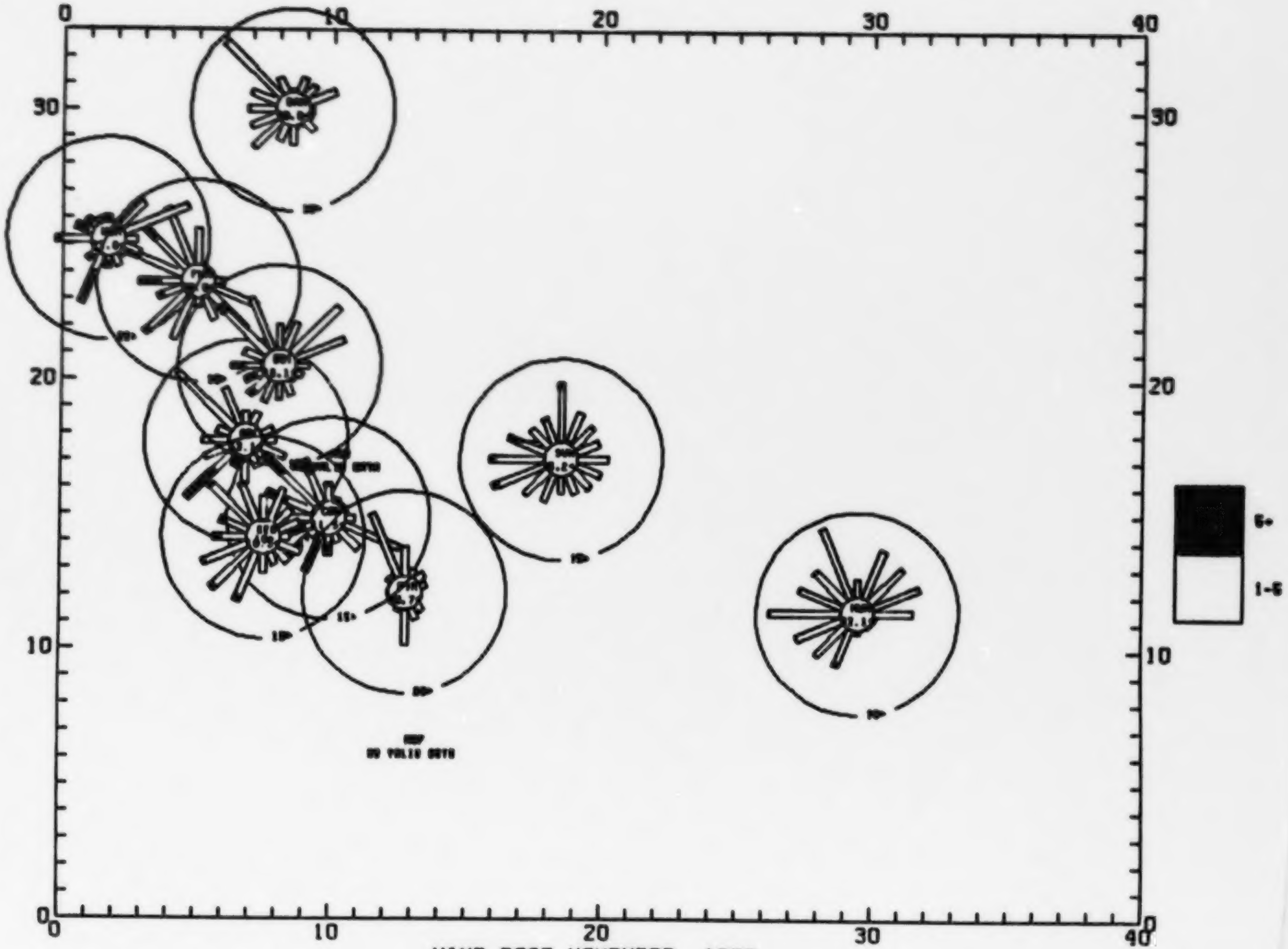

WIND RØSE AUGUST 1980
0
10
20
30
40
5+
1-5
NO VALID DATA
10
20



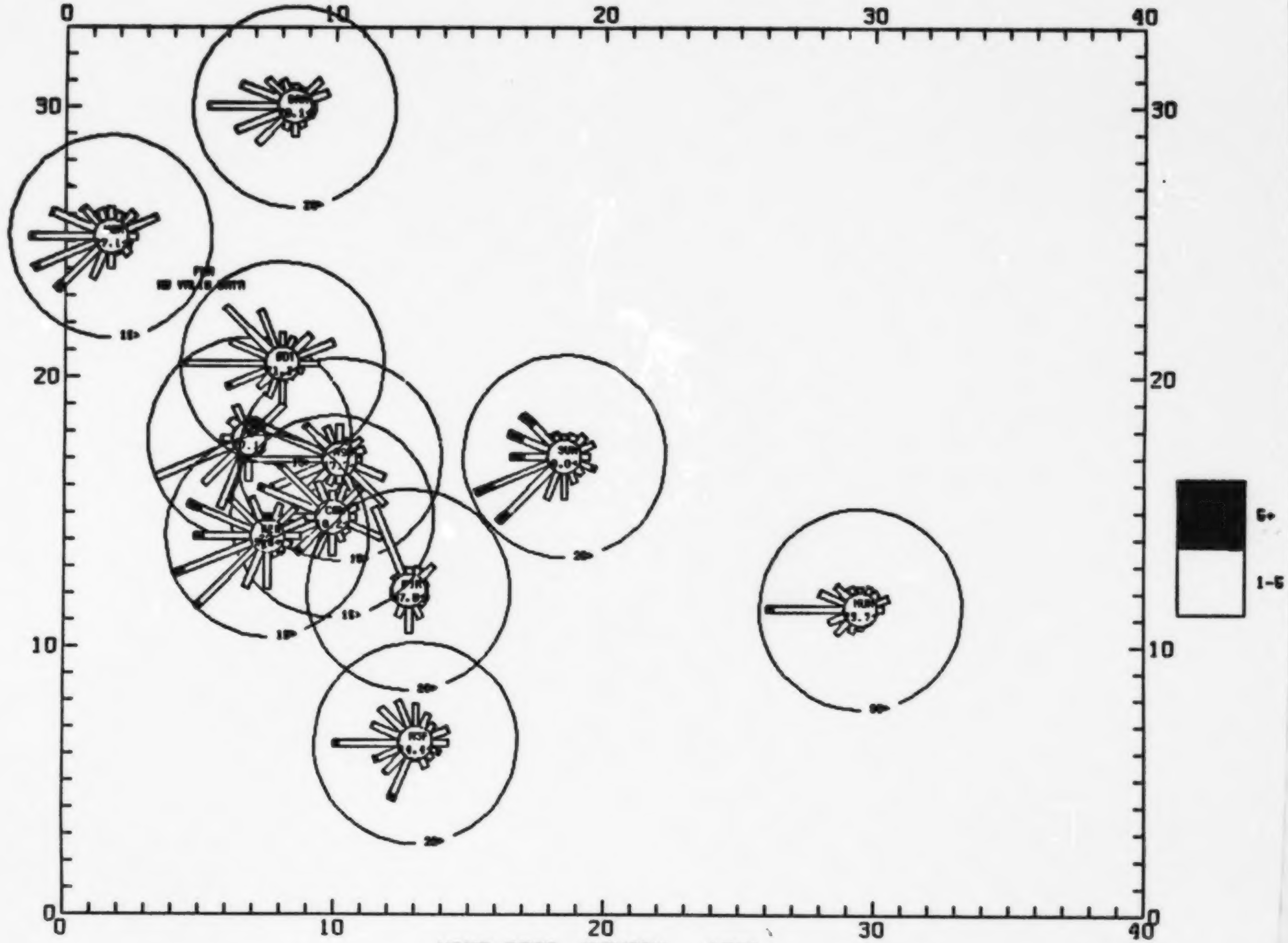
WIND RØSE SEPTEMBER 1980



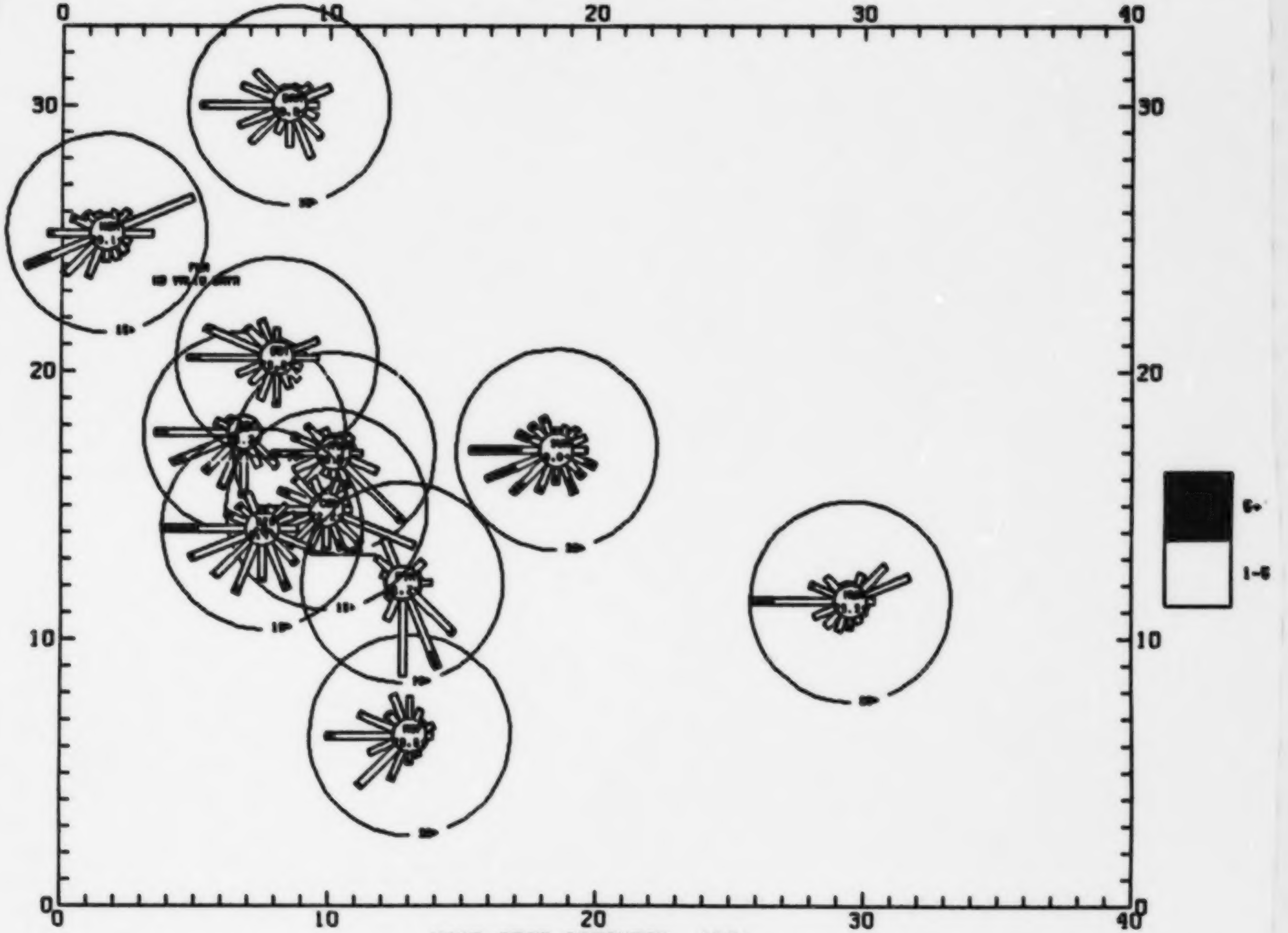
WIND RØSE ØCTØBER 1980



WIND RØSE NØVEMBER 1980



WIND RØSE JANUARY 1981



WIND RØSE FEBRUARY 1981

APPENDIX B

SCATTER PLOTS AND REGRESSION LINES OF STATION VARIABLES AND CORRESPONDING NWS VARIABLES

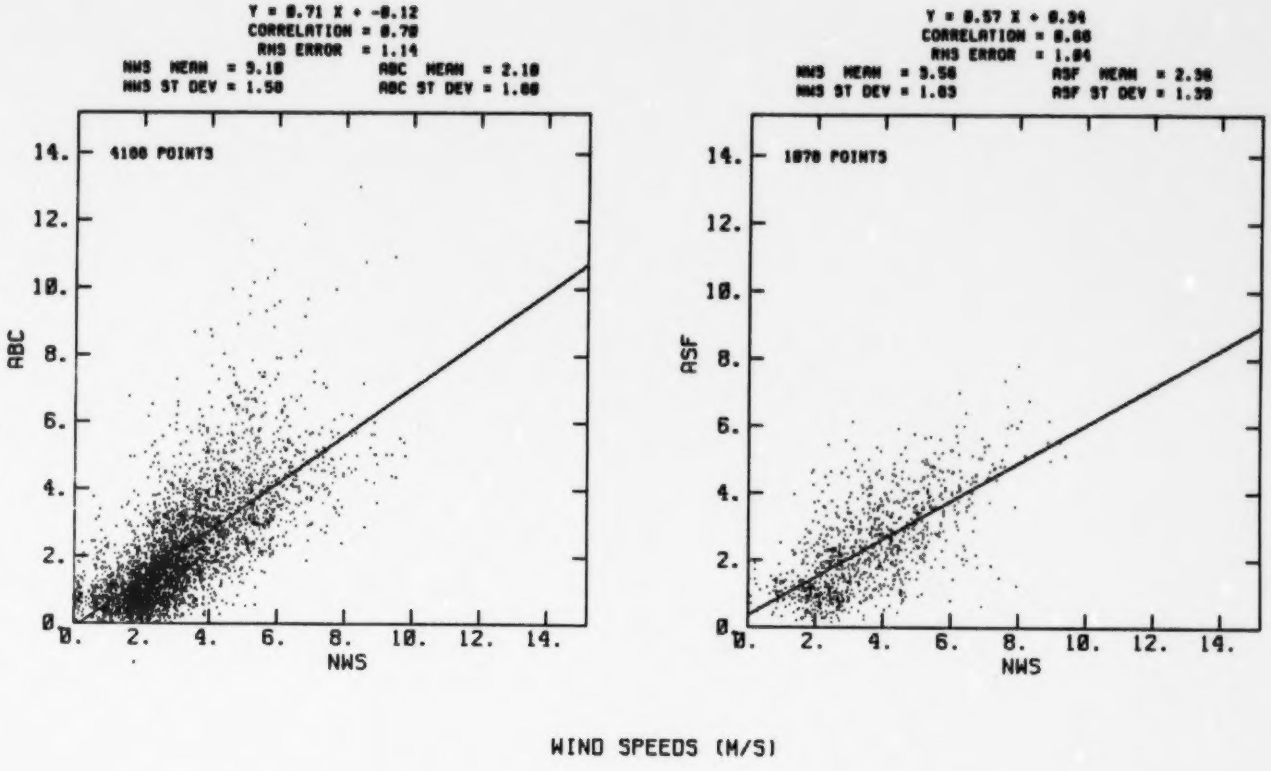


Figure B-1. Regression and scatter plots showing correlation of NWS data with data from the twelve network stations for all hours.

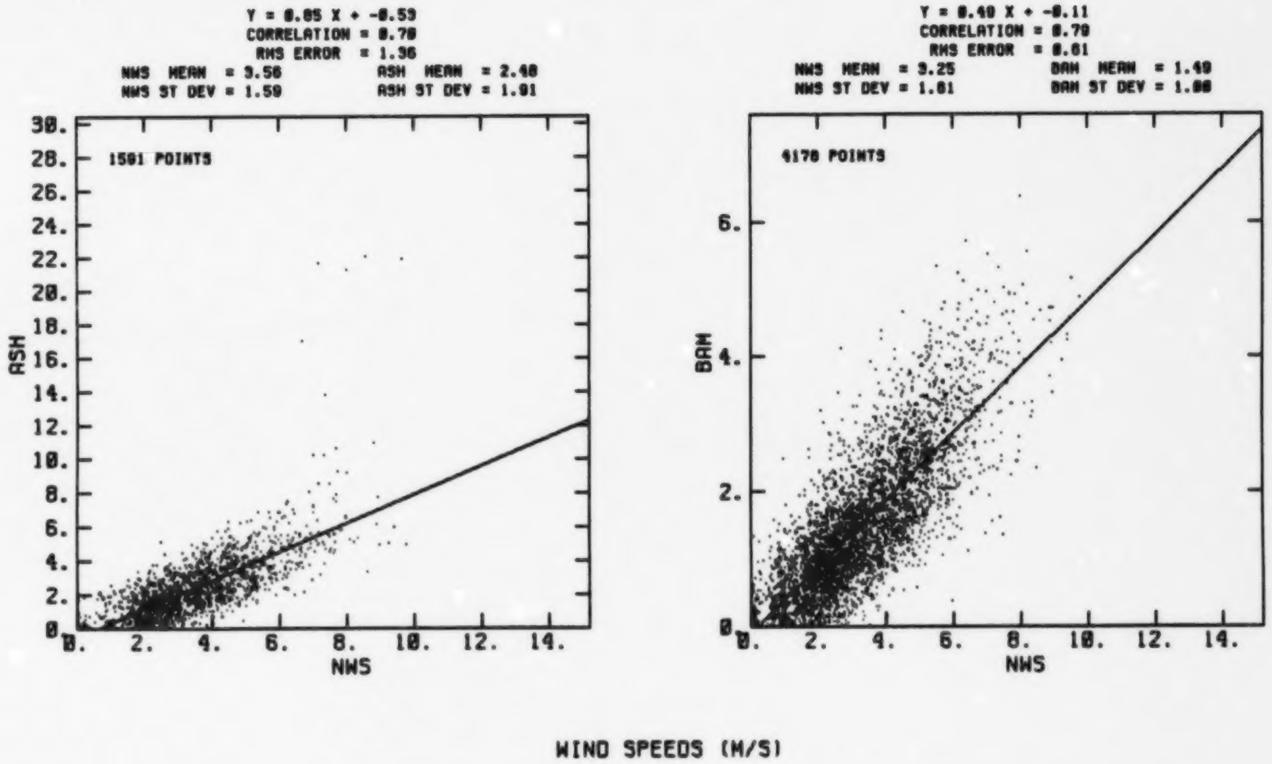


Figure B-1. (Continued)

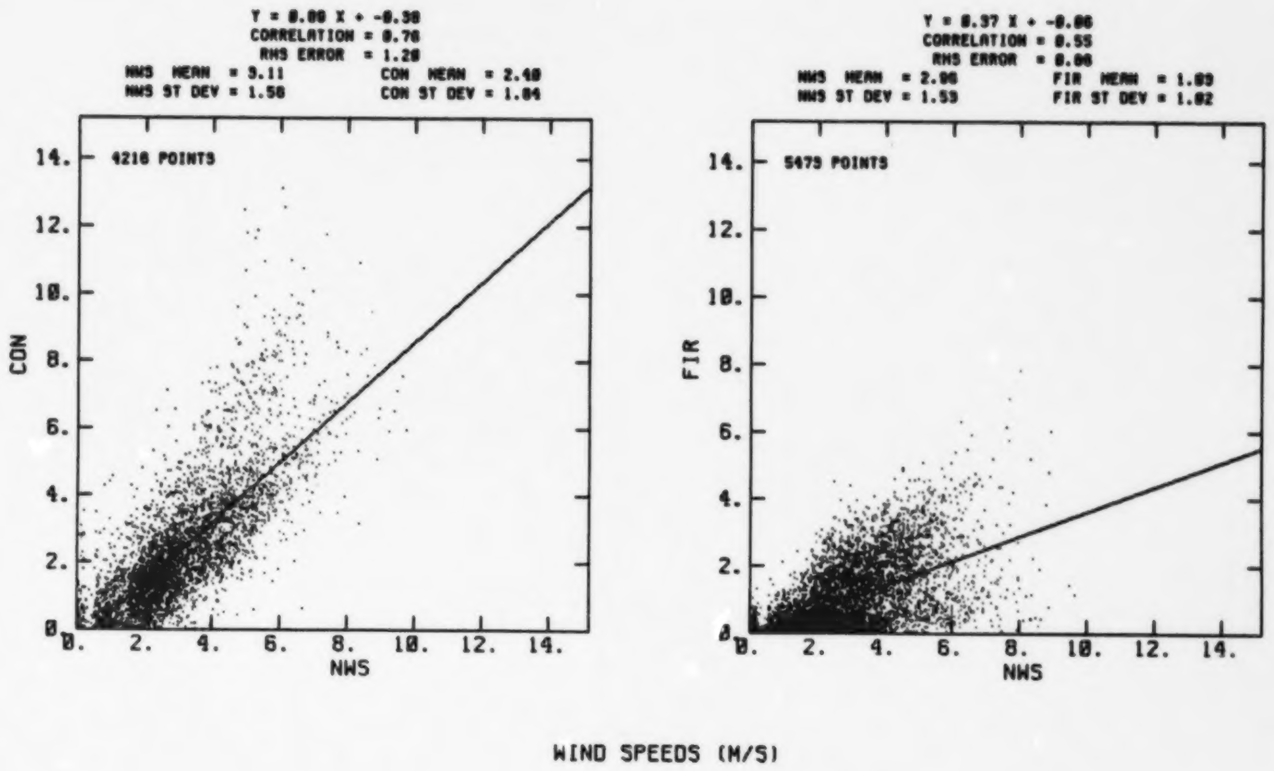


Figure B-1. (Continued)

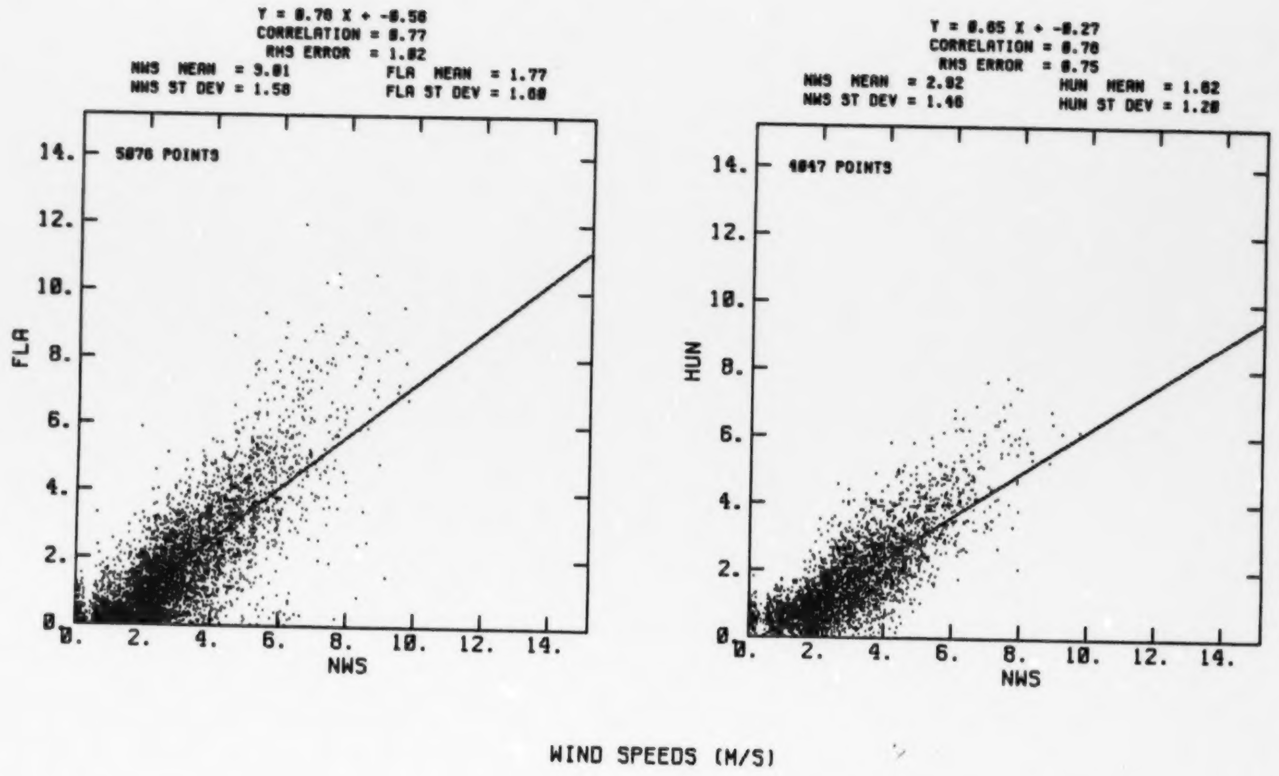


Figure B-1. (Continued)

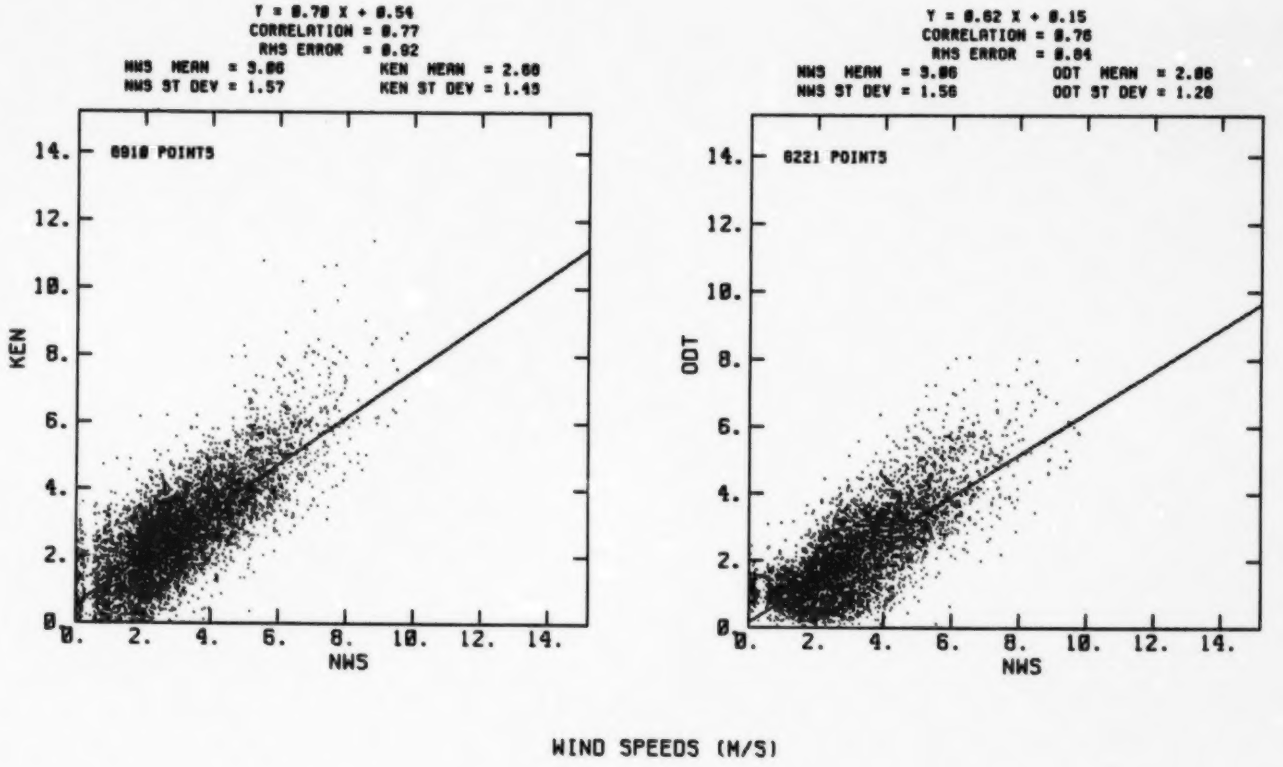


Figure B-1. (Continued)

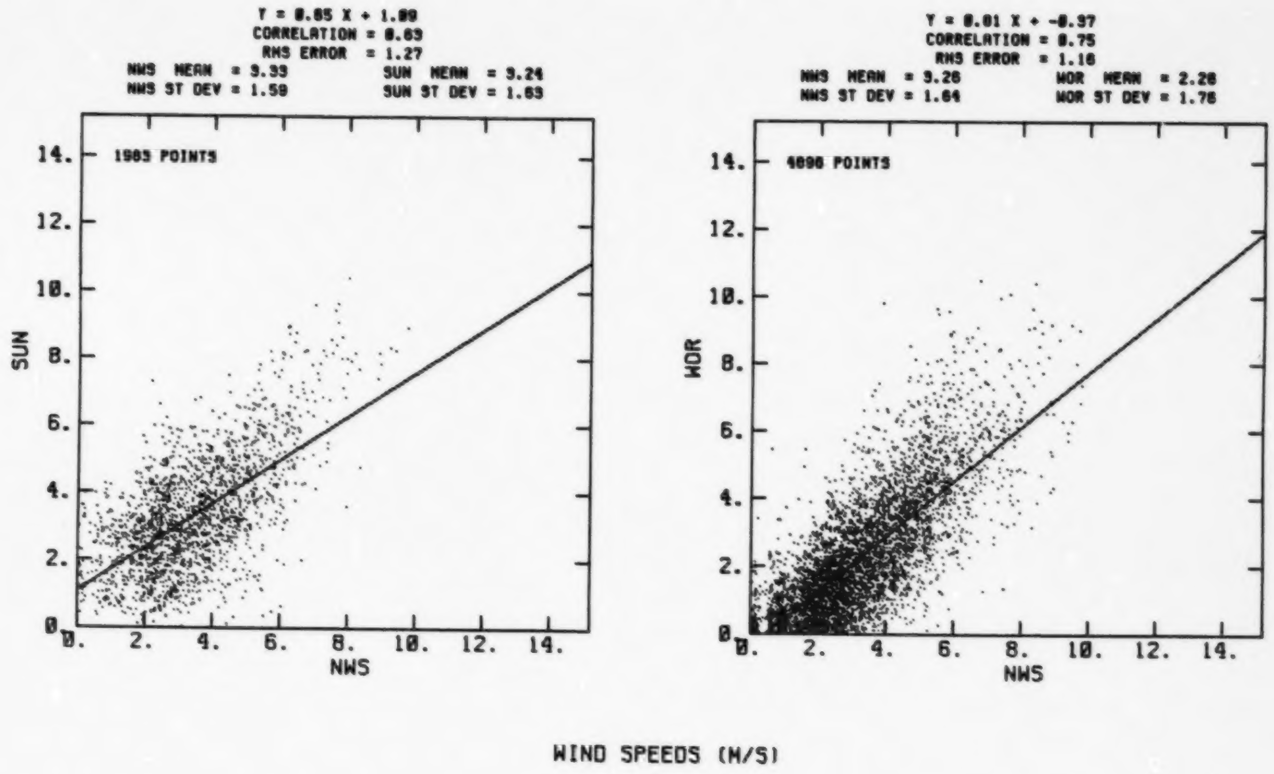


Figure B-1. (Continued)

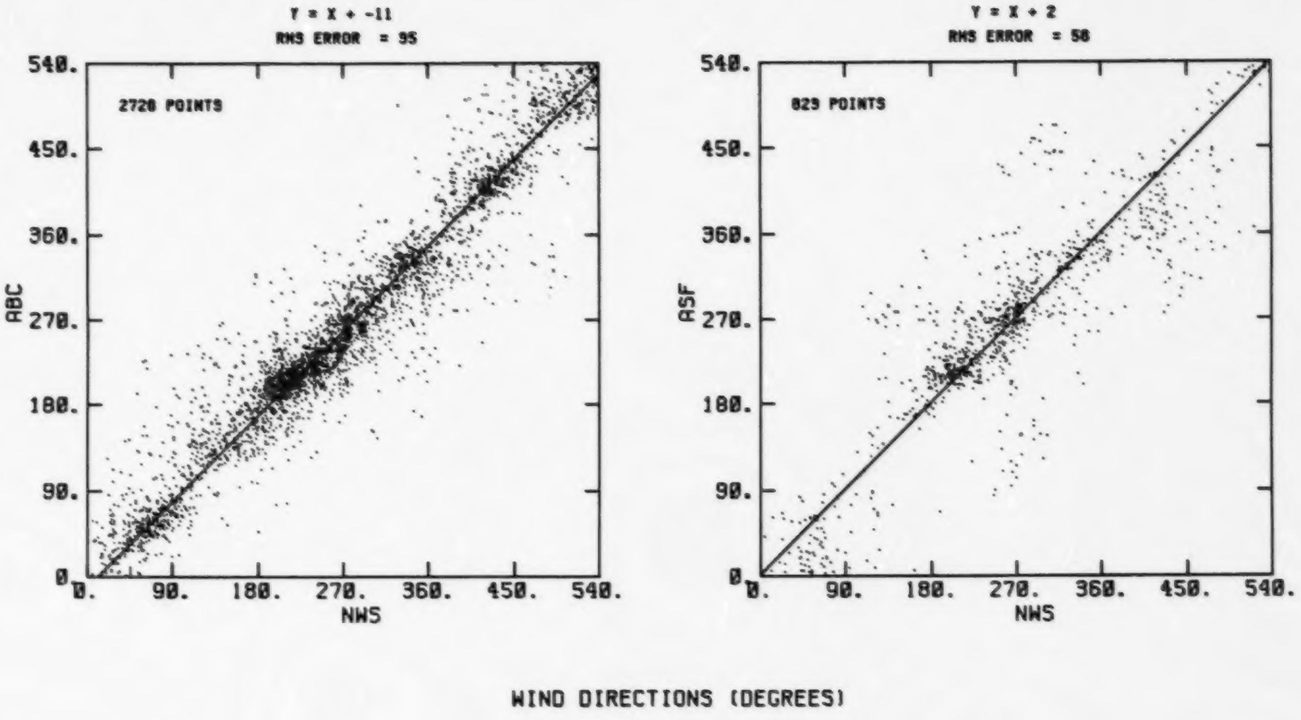


Figure B-1. (Continued)

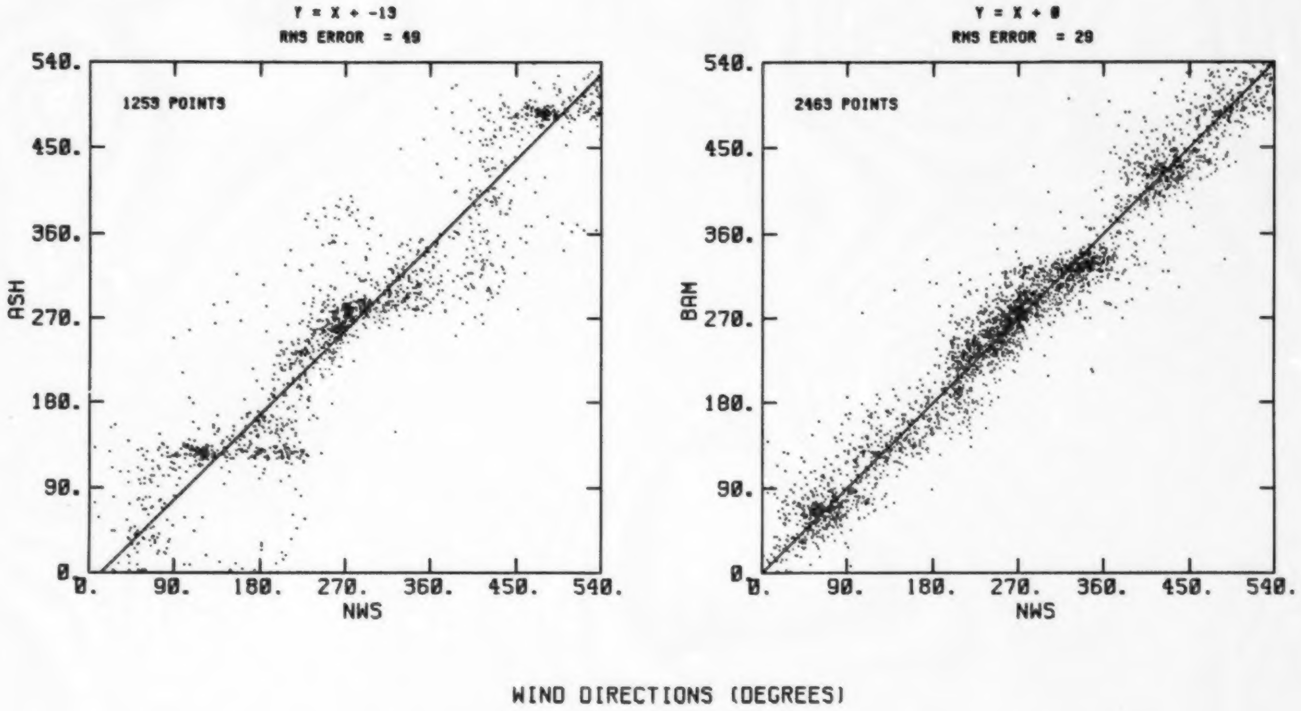


Figure B-1. (Continued)

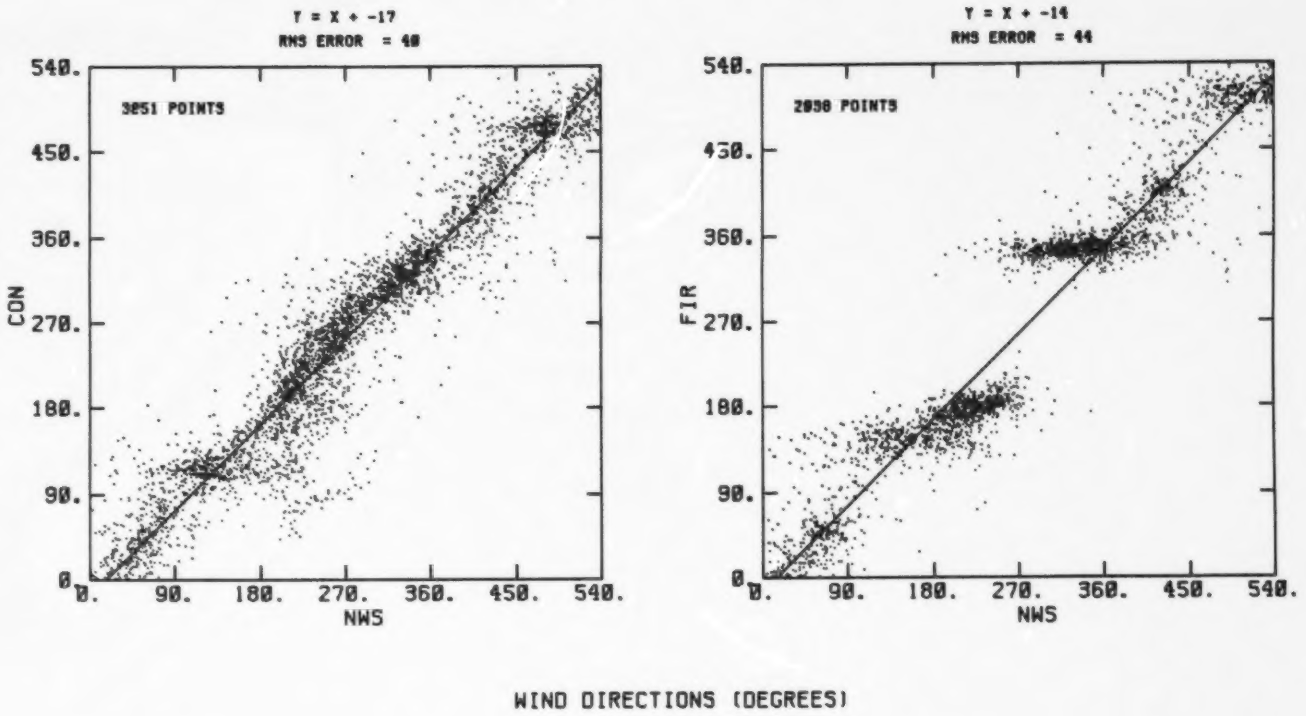


Figure B-1. (Continued)

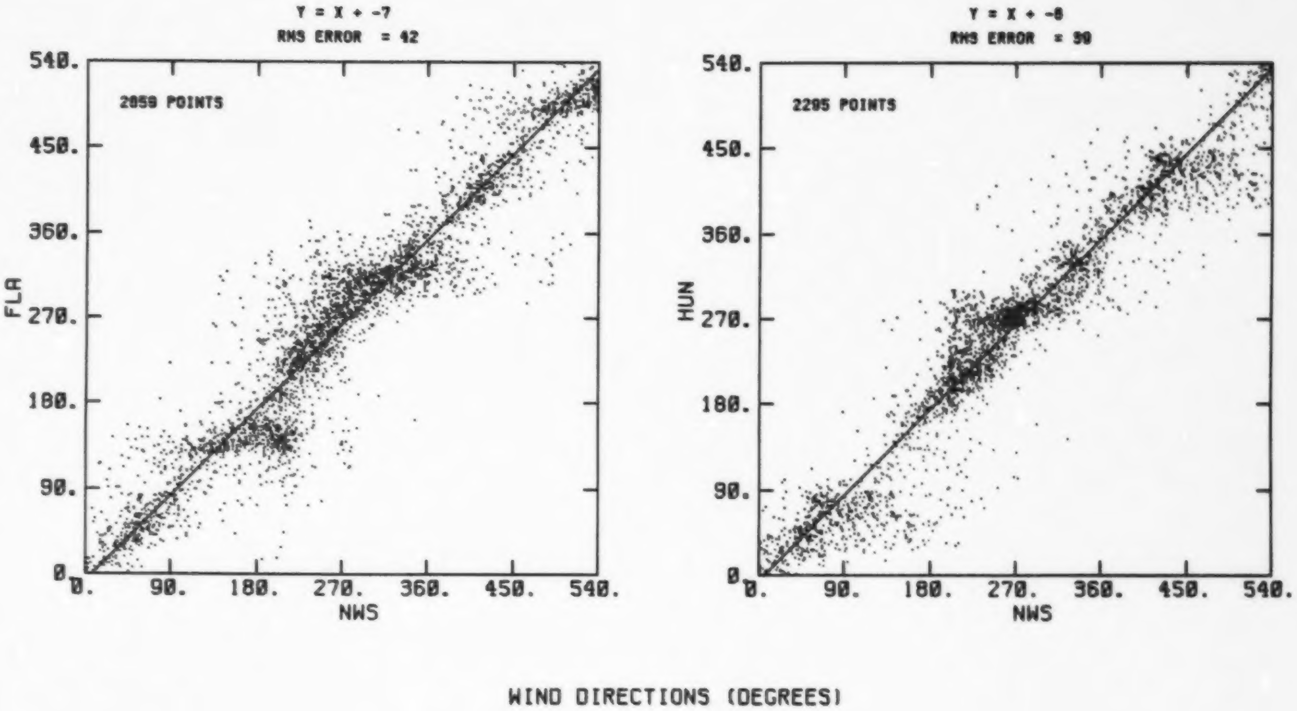


Figure B-1. (Continued)

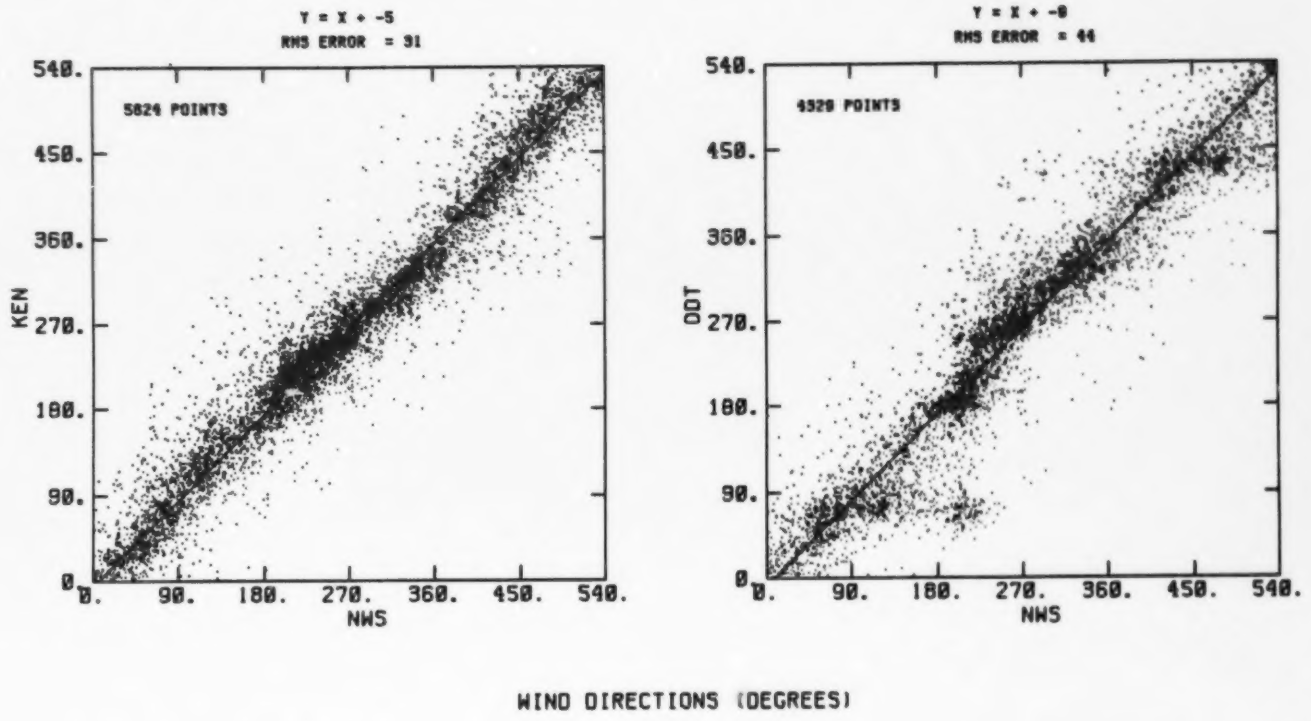


Figure B-1. (Continued)

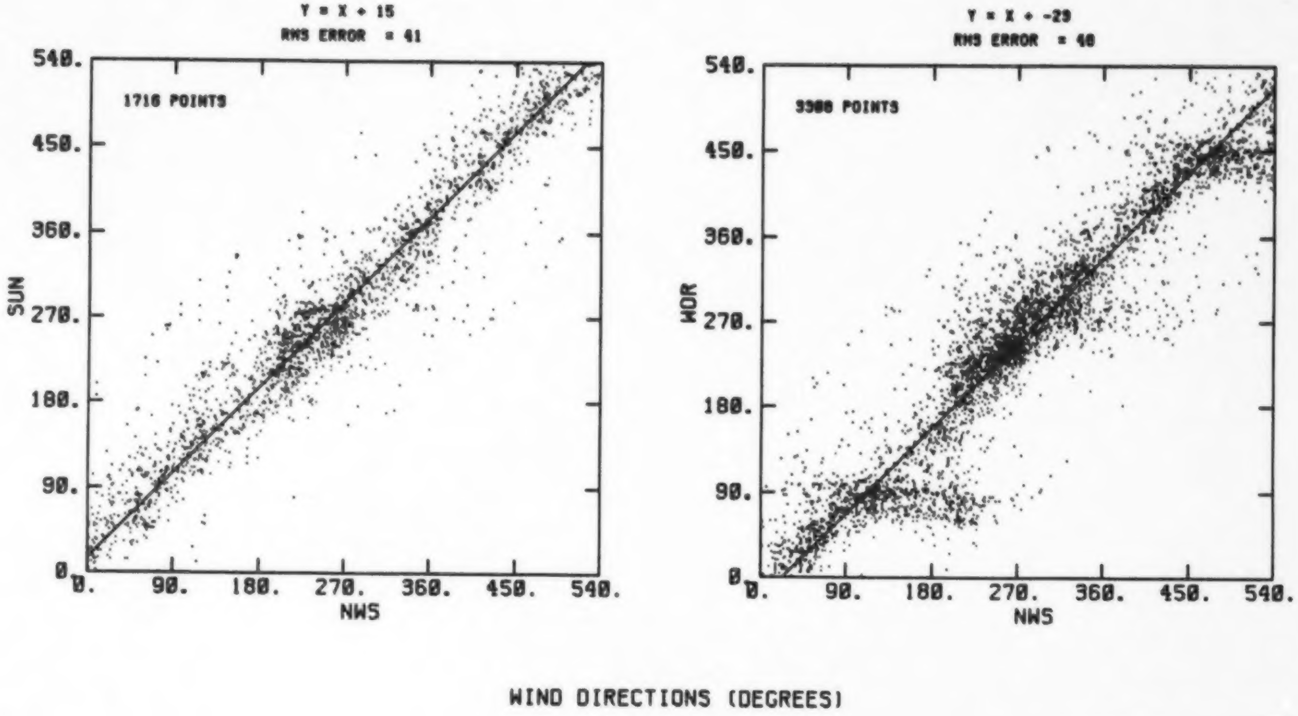


Figure B-1. (Continued)

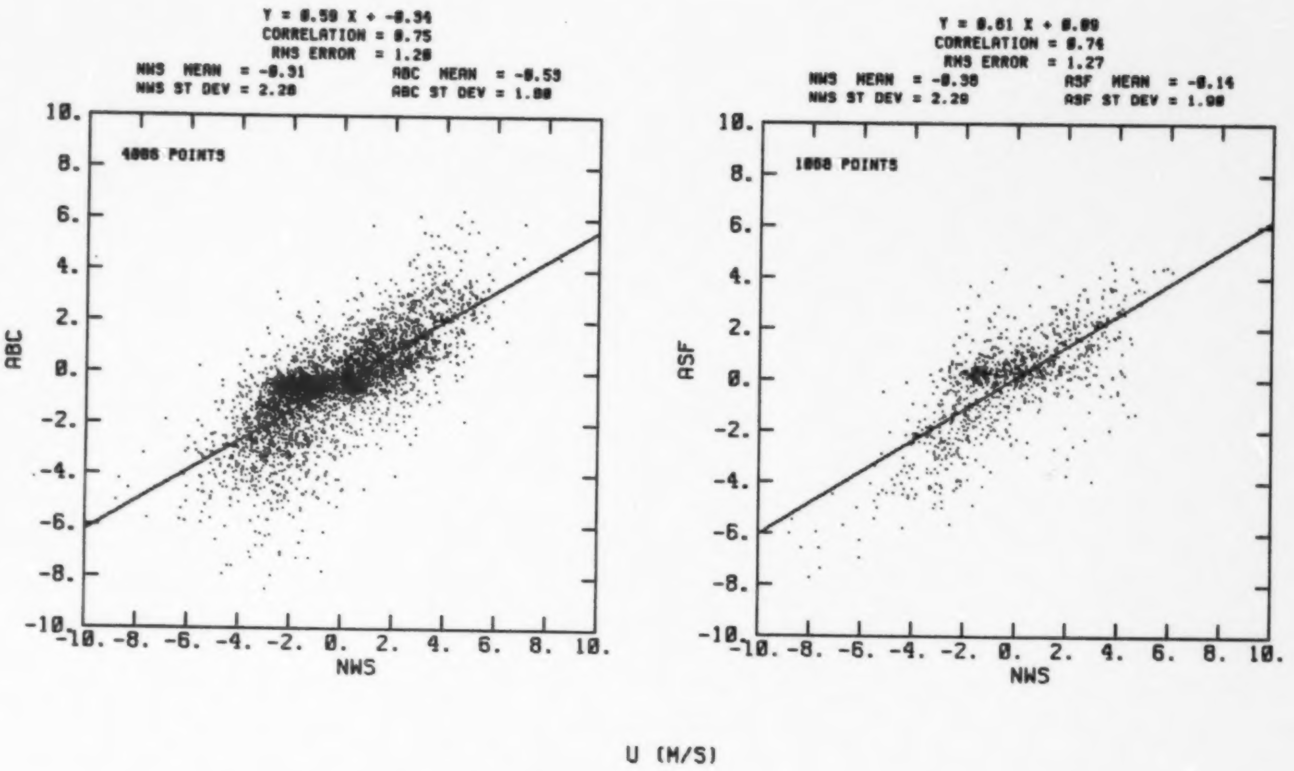


Figure B-1. (Continued)

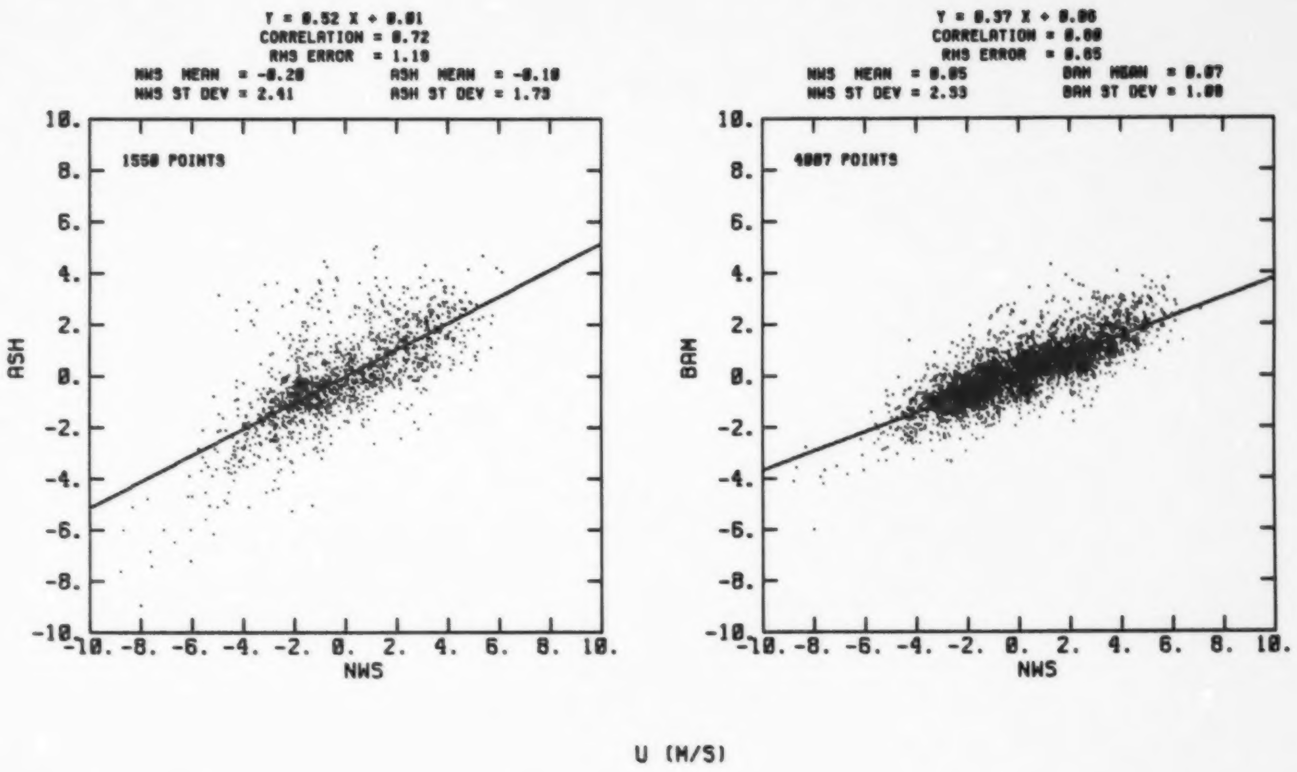


Figure B-1. (Continued)

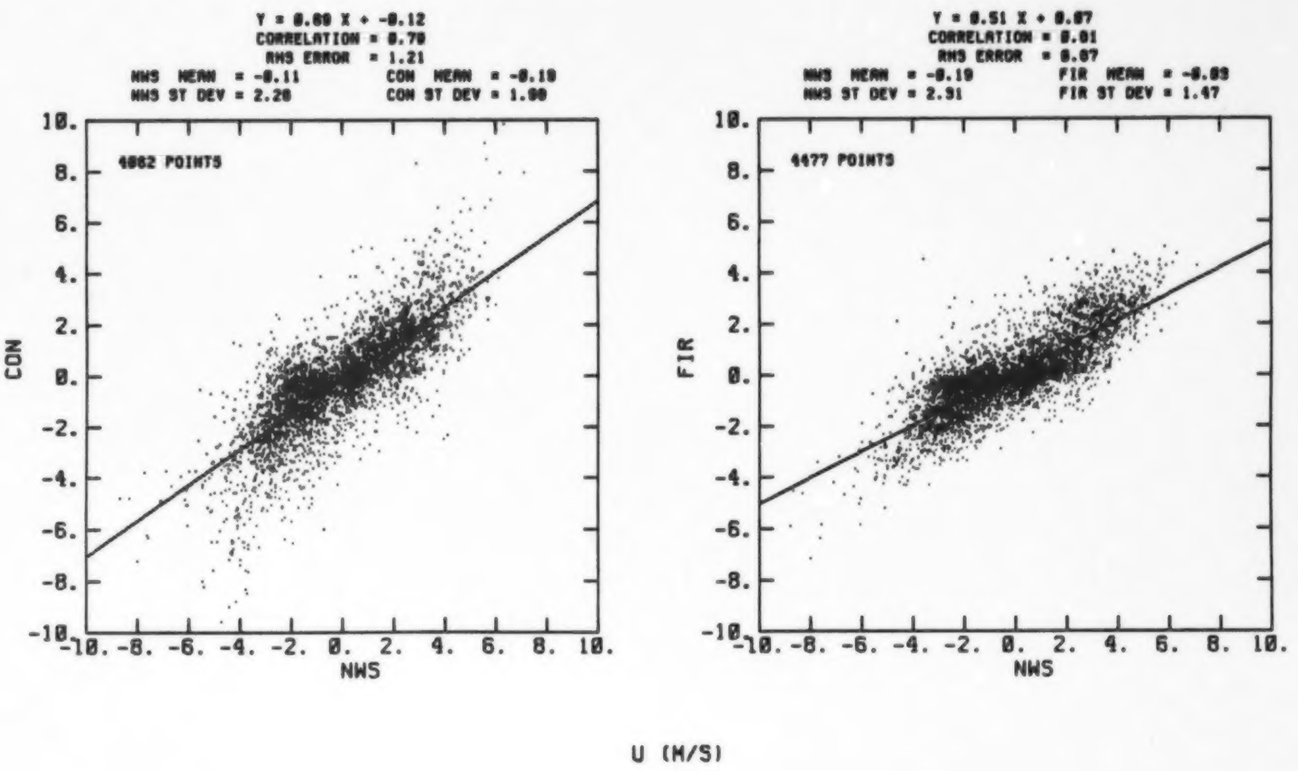


Figure B-1. (Continued)

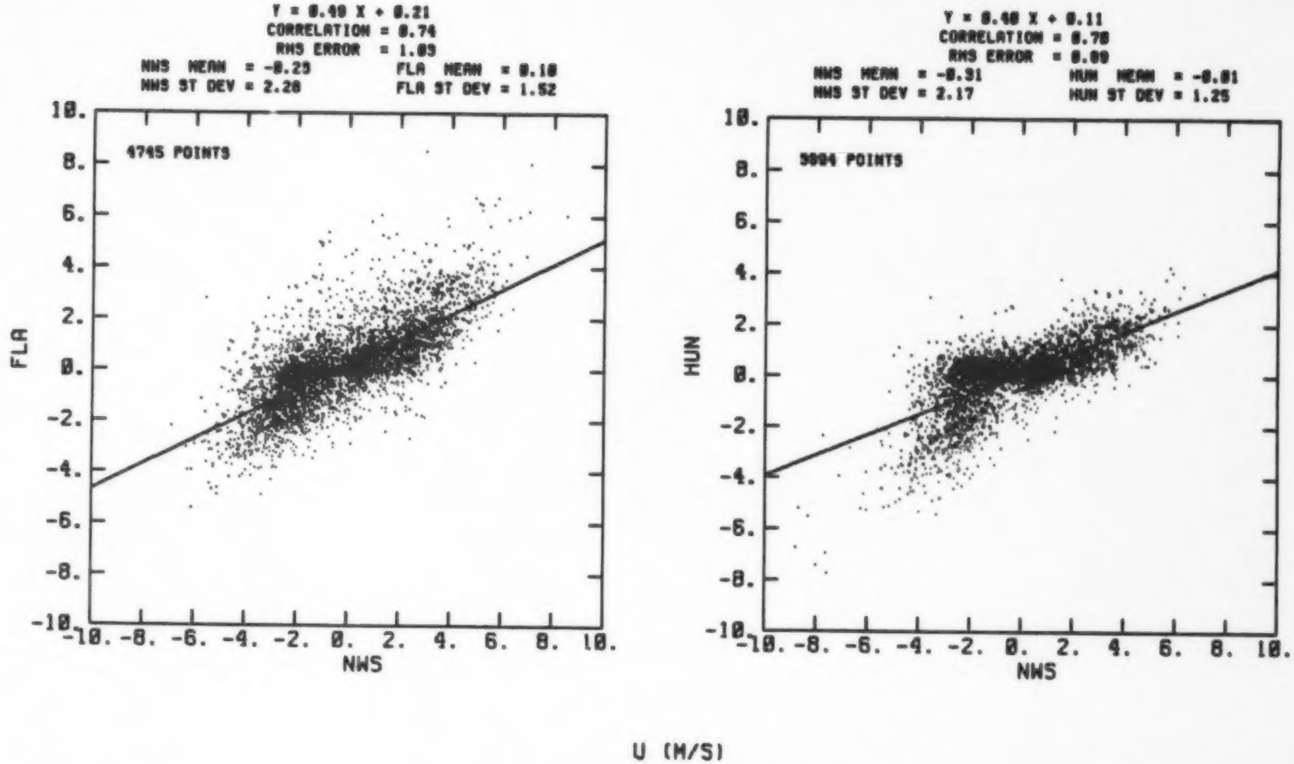


Figure B-1. (Continued)

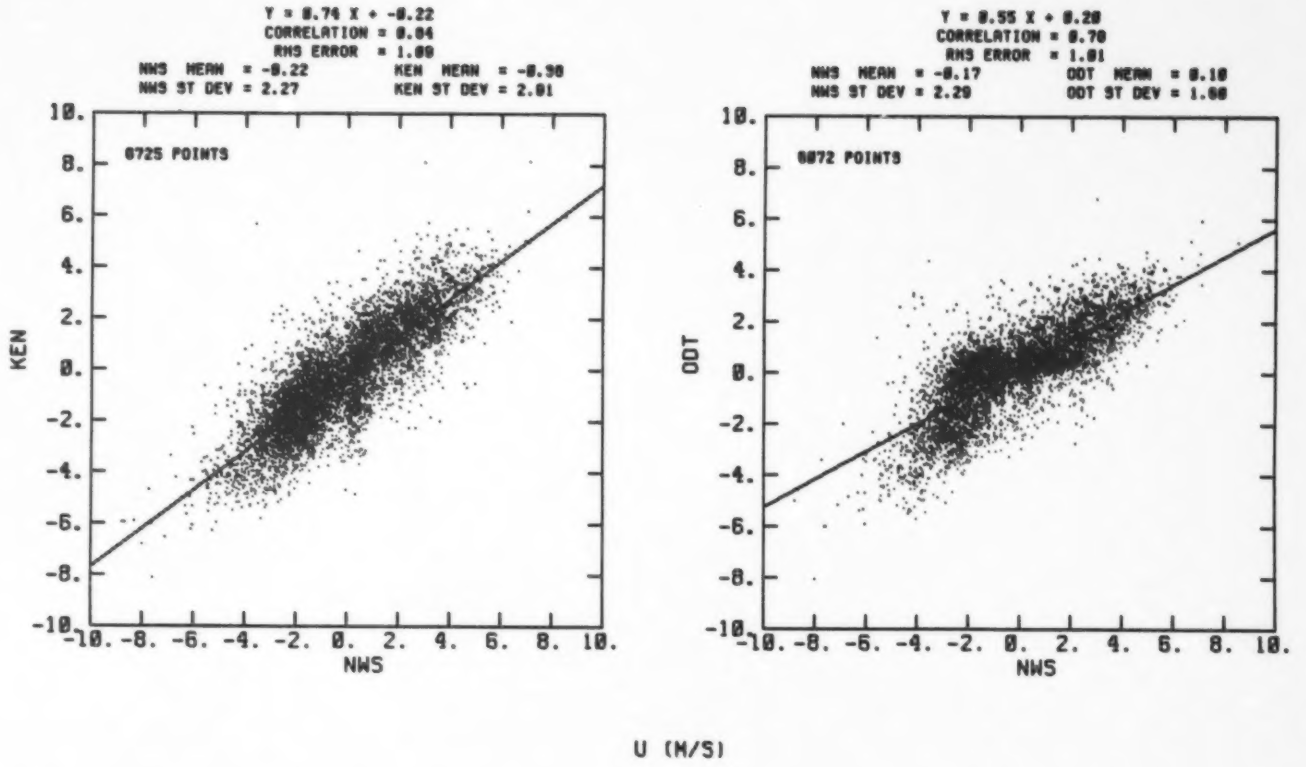


Figure B-1. (Continued)

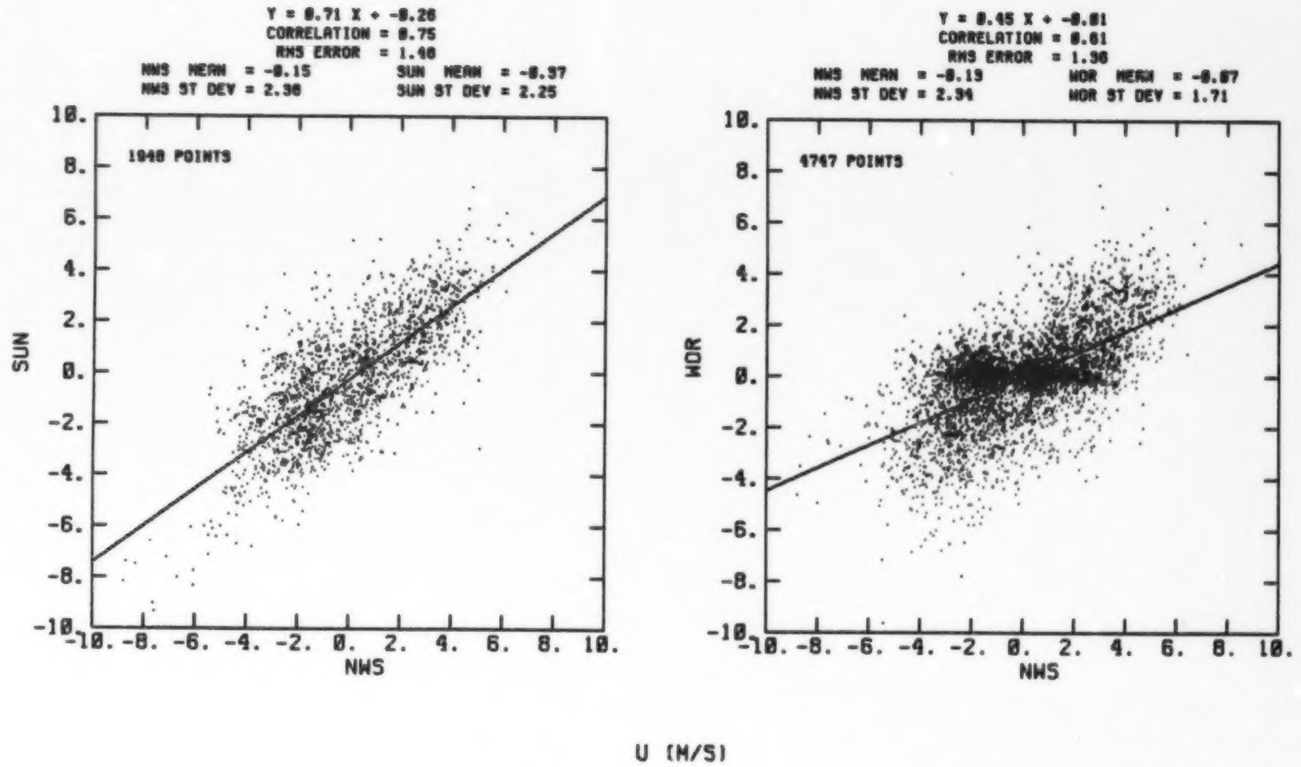


Figure B-1. (Continued)

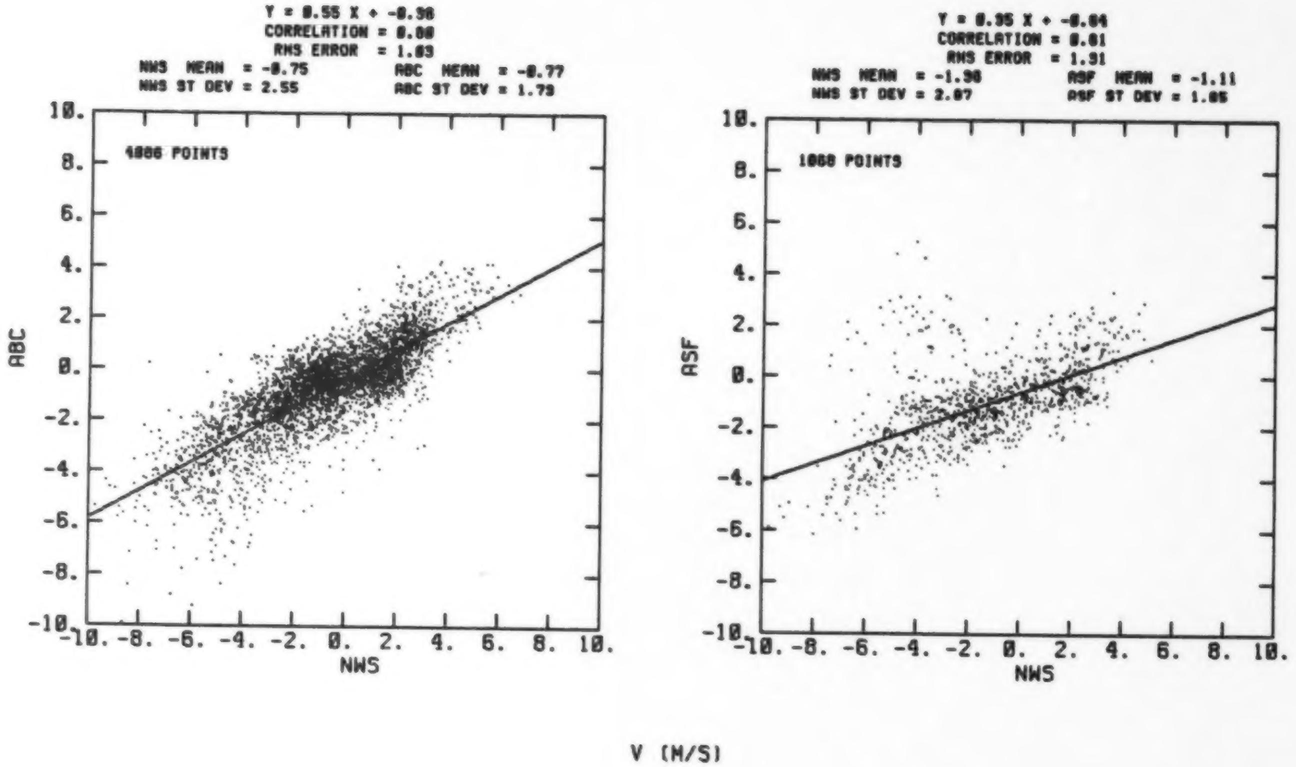


Figure B-1. (Continued)

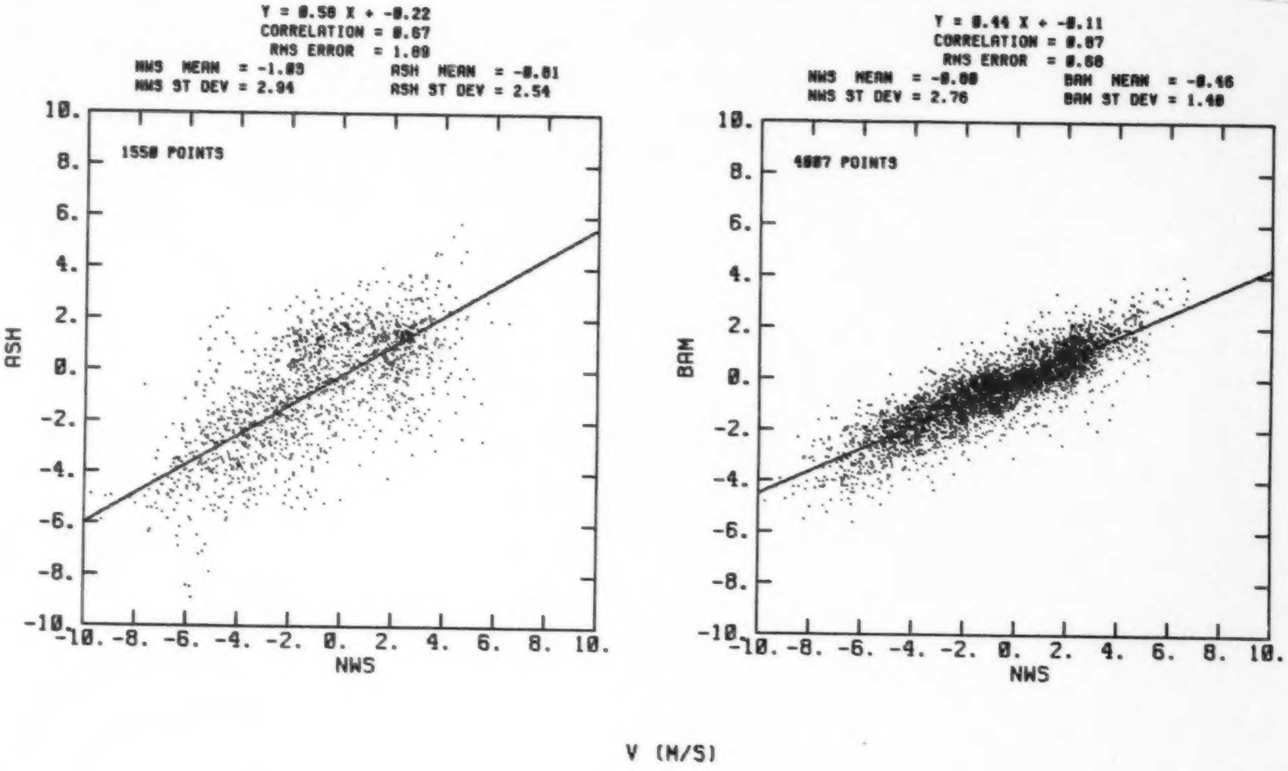


Figure B-1. (Continued)

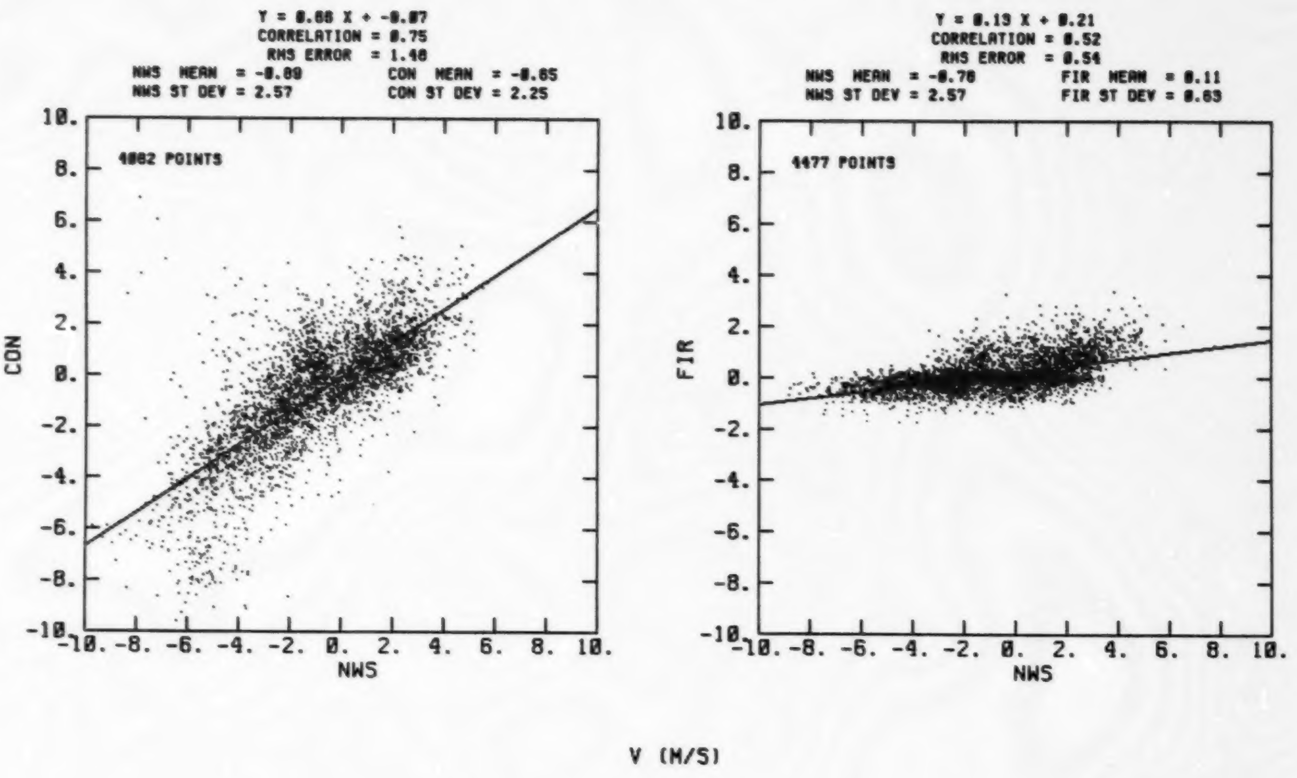


Figure B-1. (Continued)

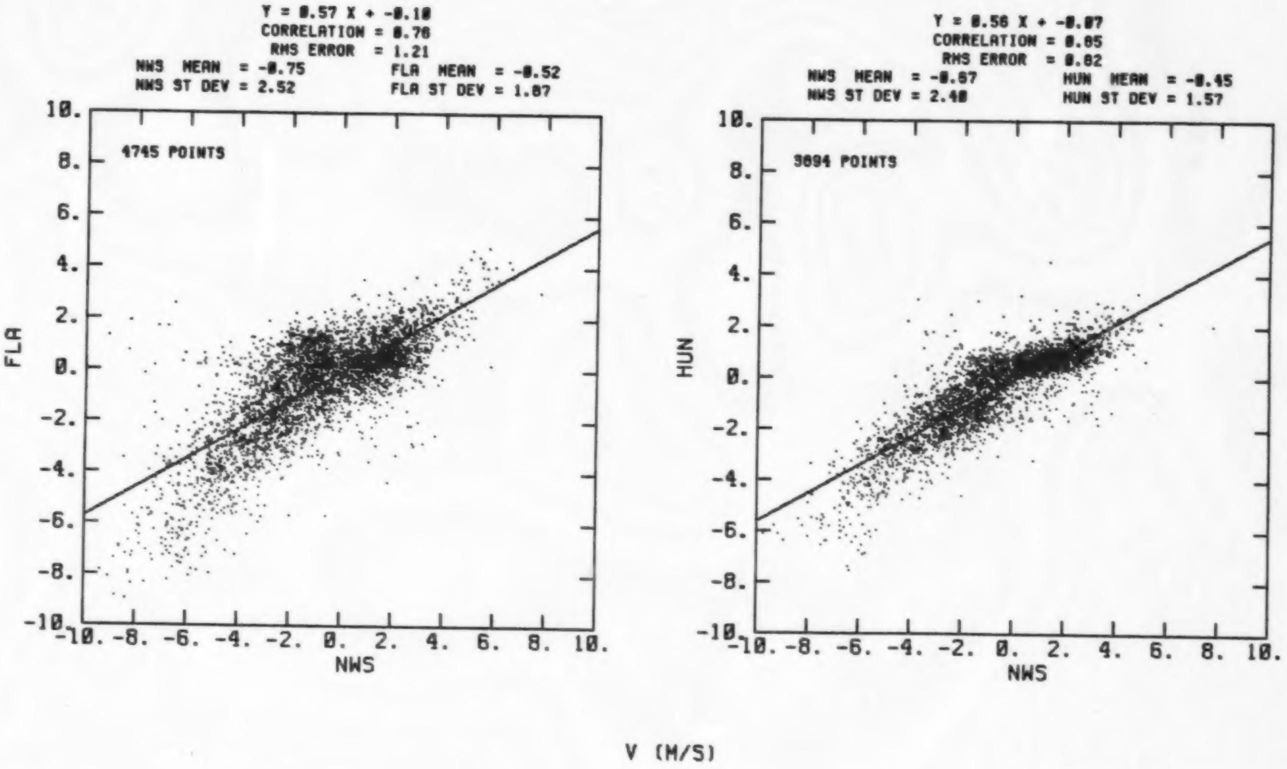


Figure B-1. (Continued)

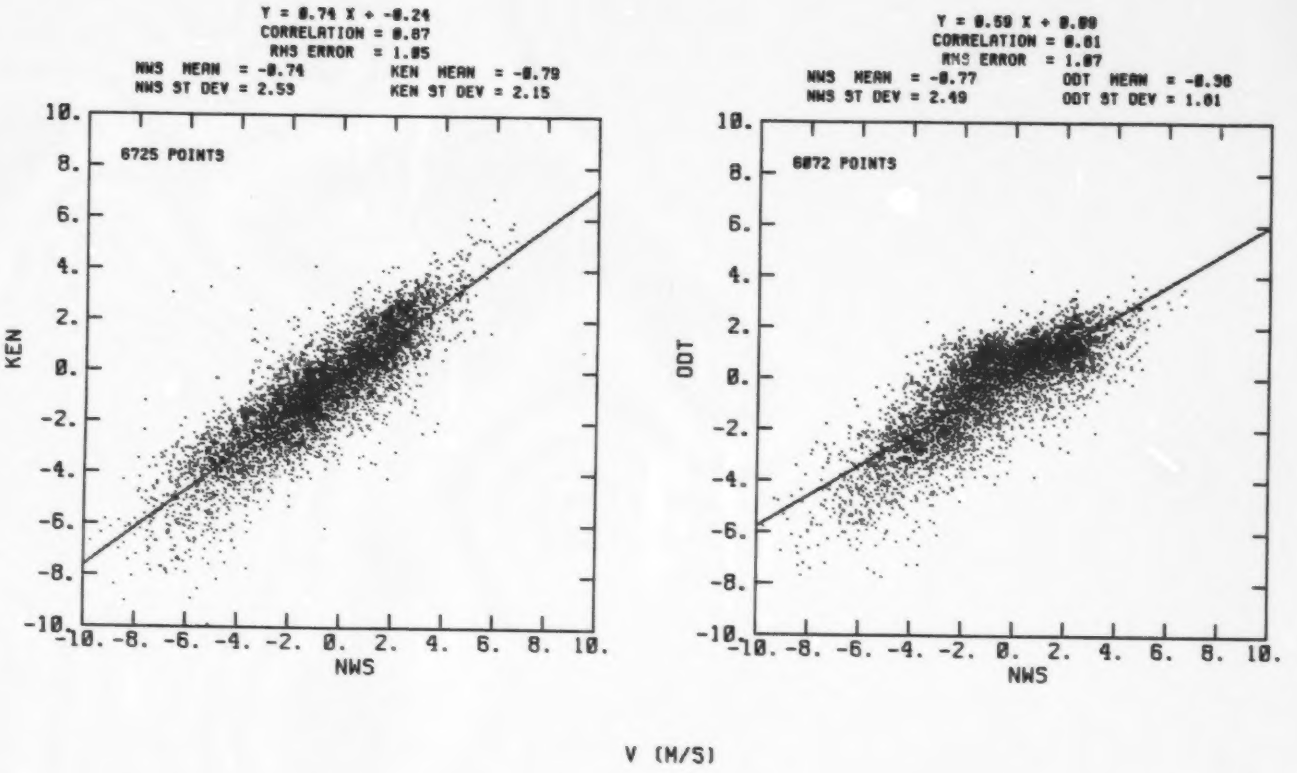


Figure B-1. (Continued)

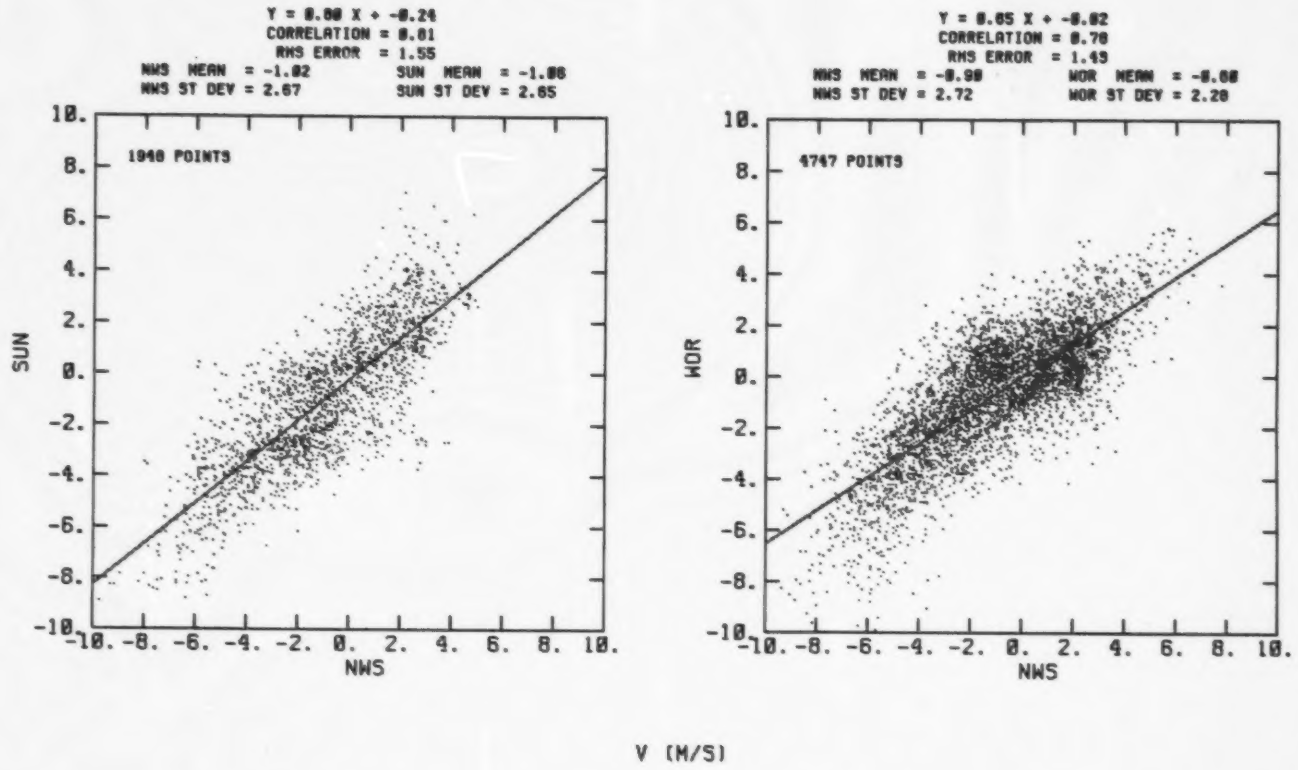
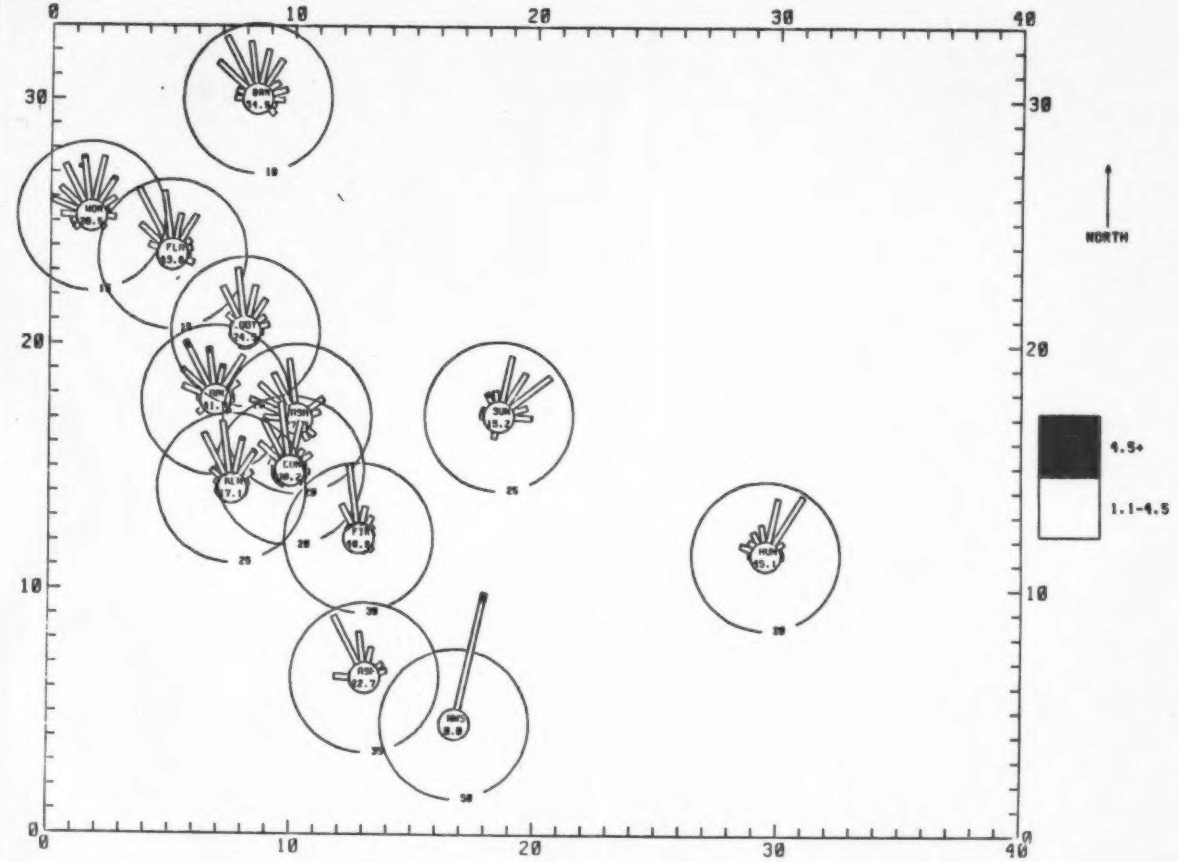


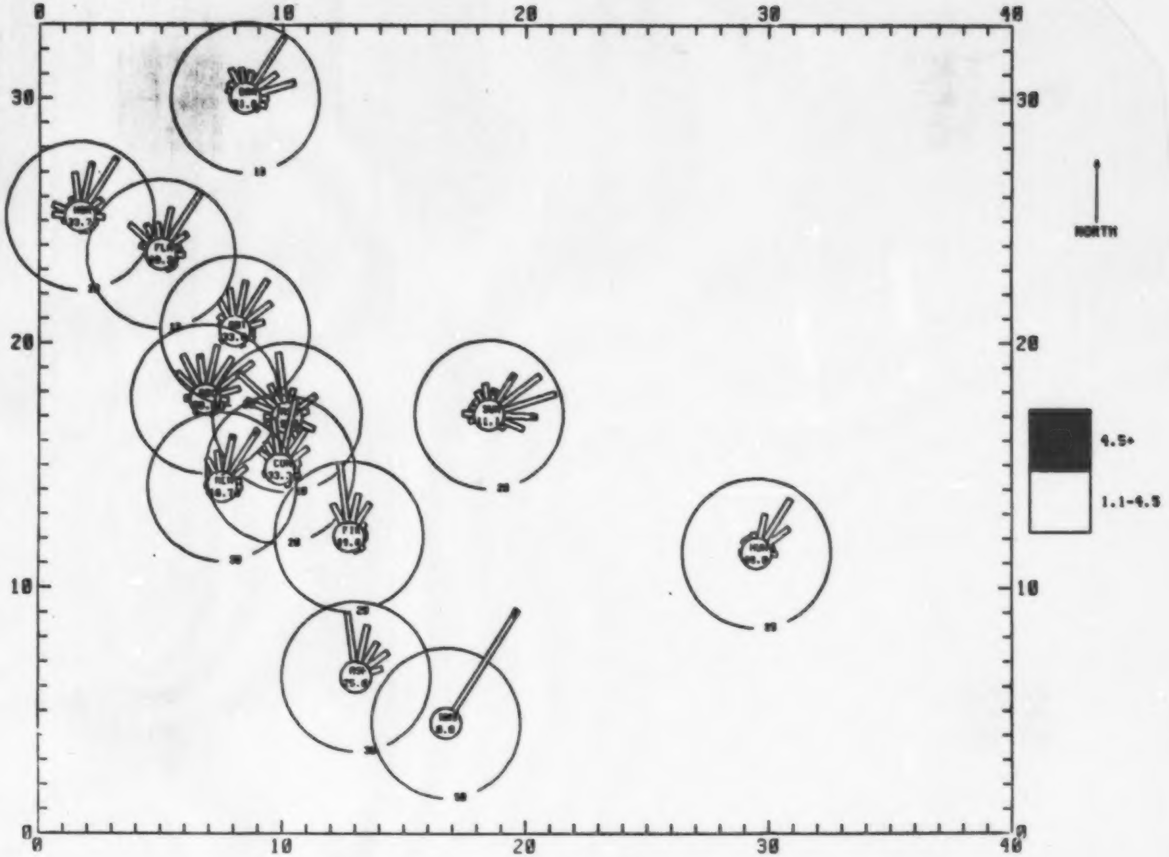
Figure B-1. (Concluded)

APPENDIX C

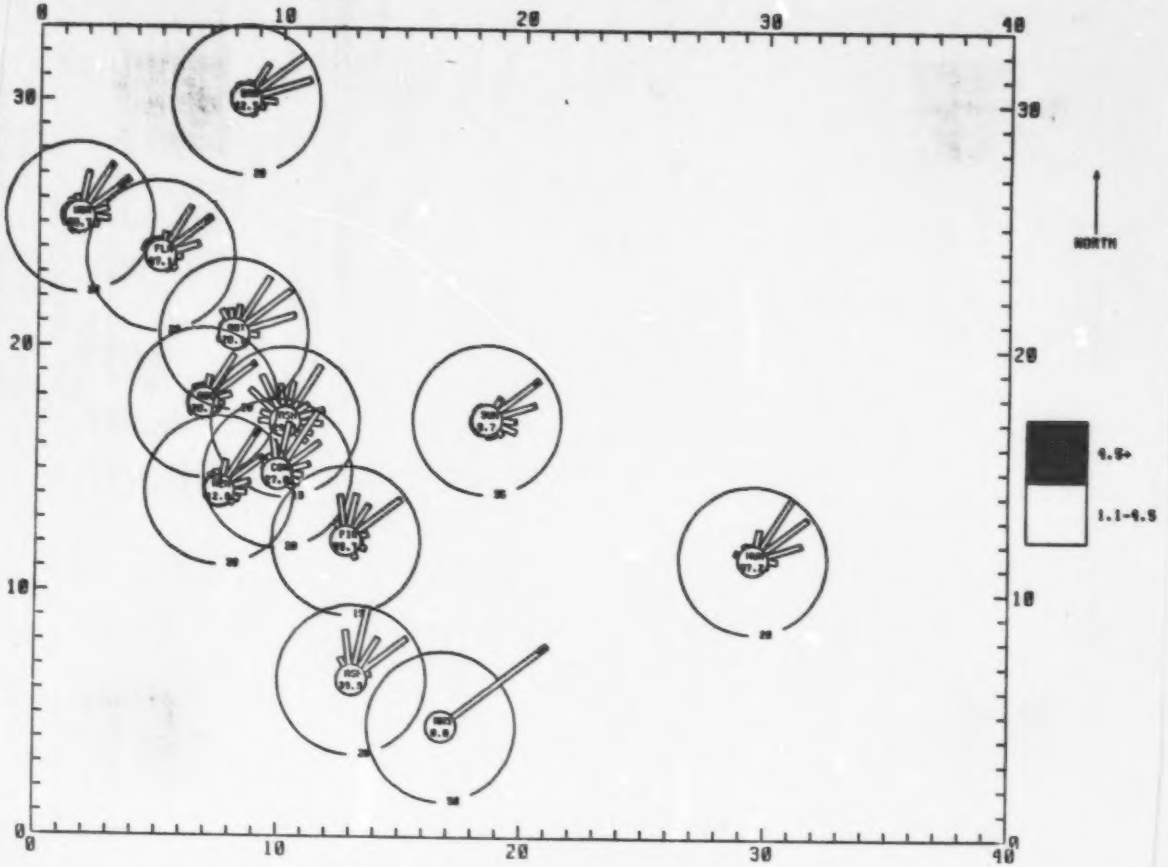
STATION WIND ROSES STRATIFIED BY NWS WIND DIRECTION



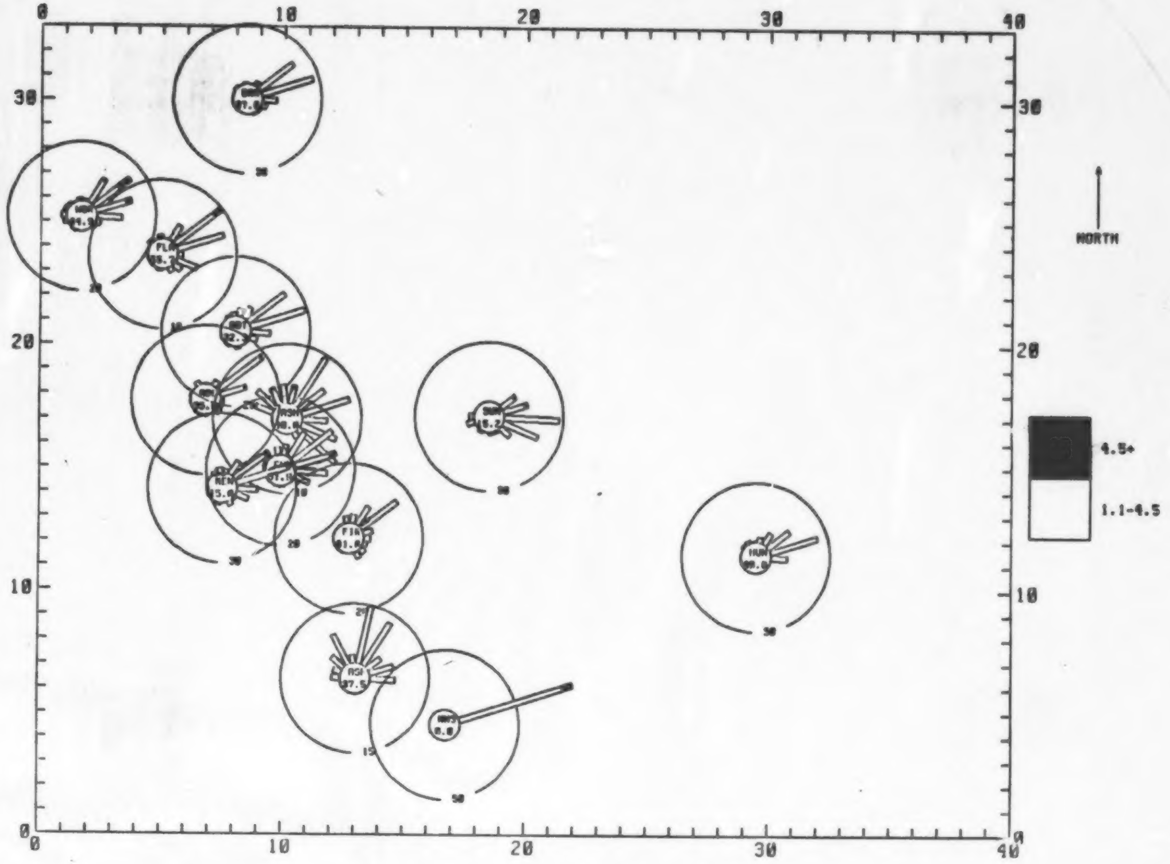
BIN 1 314 OCCURRENCES
WIND SPEED 1.10 AND UP
WIND DIRECTION 2.50 TO 22.50



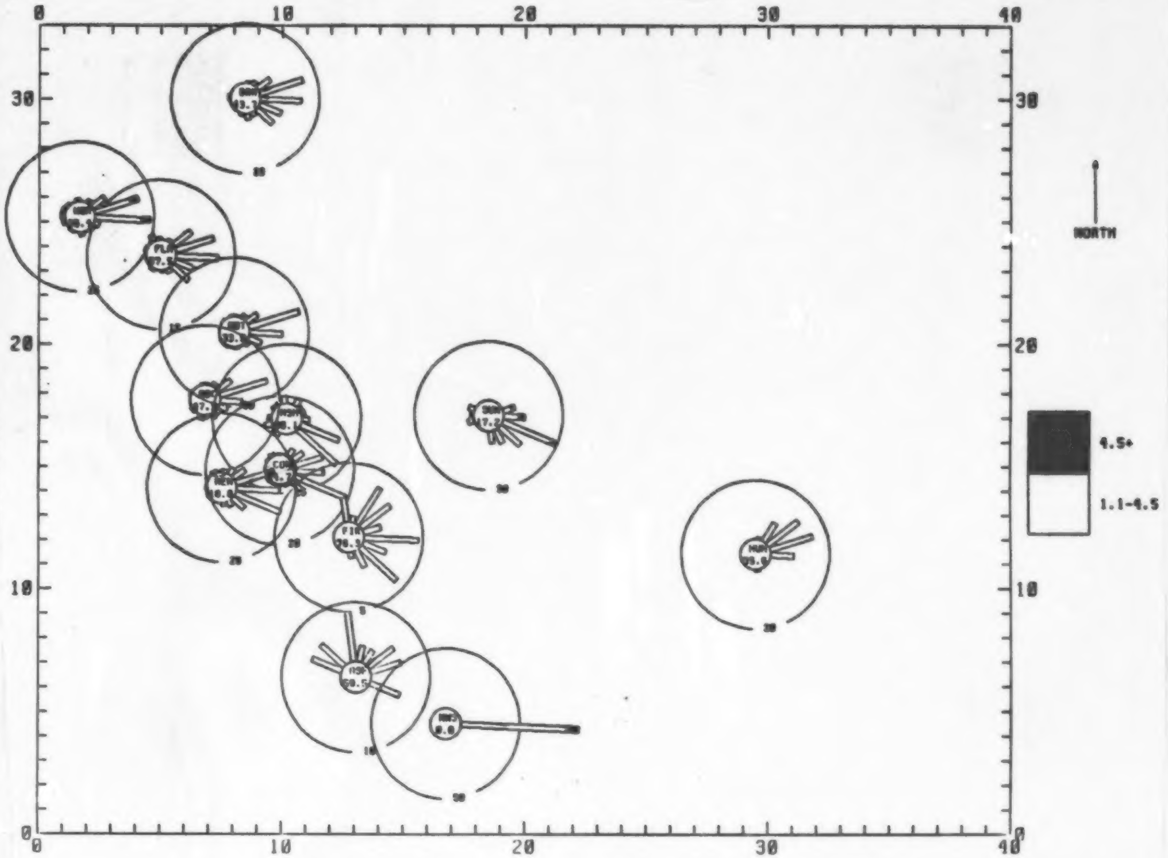
BIN 2 324 OCCURRENCES
WIND SPEED 1.10 AND UP
WIND DIRECTION 22.50 TO 42.50



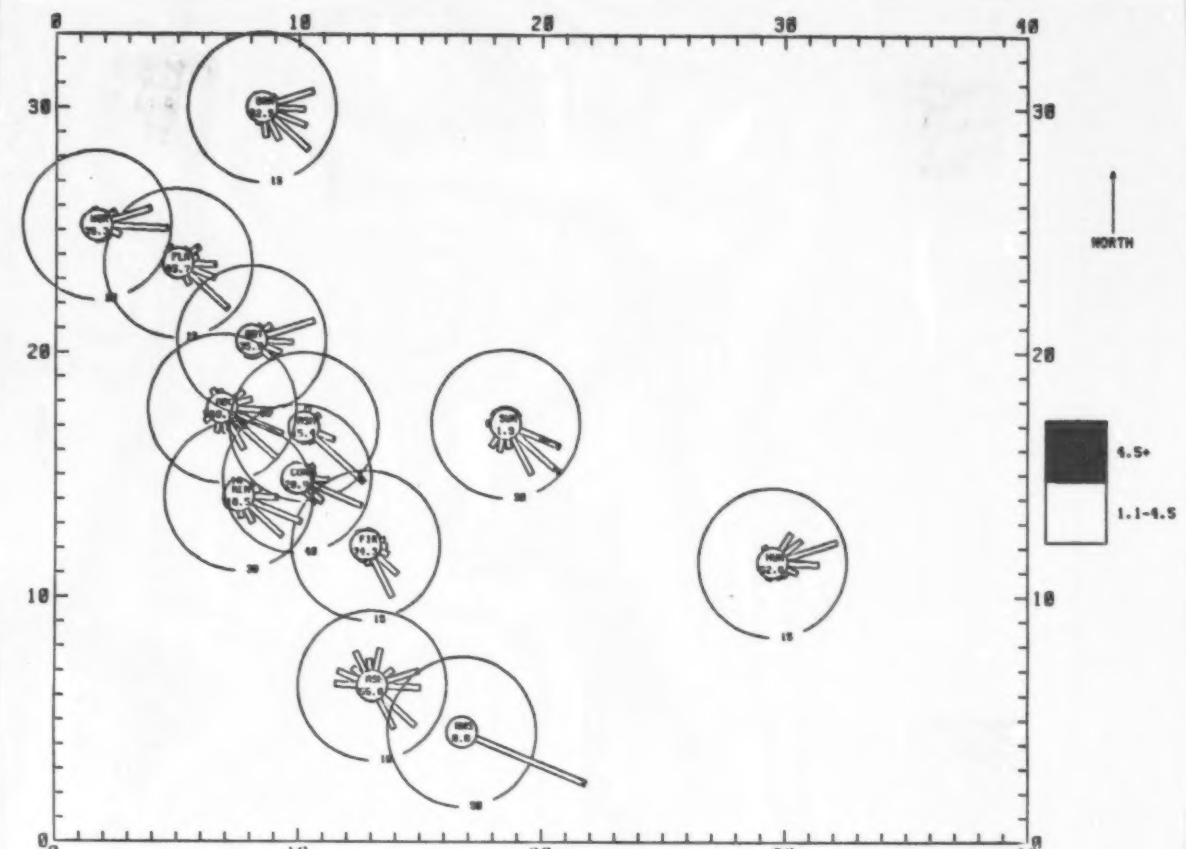
DIN 3 430 OCCURRENCES
WIND SPEED 1.10 AND UP
WIND DIRECTION 42.50 TO 62.50



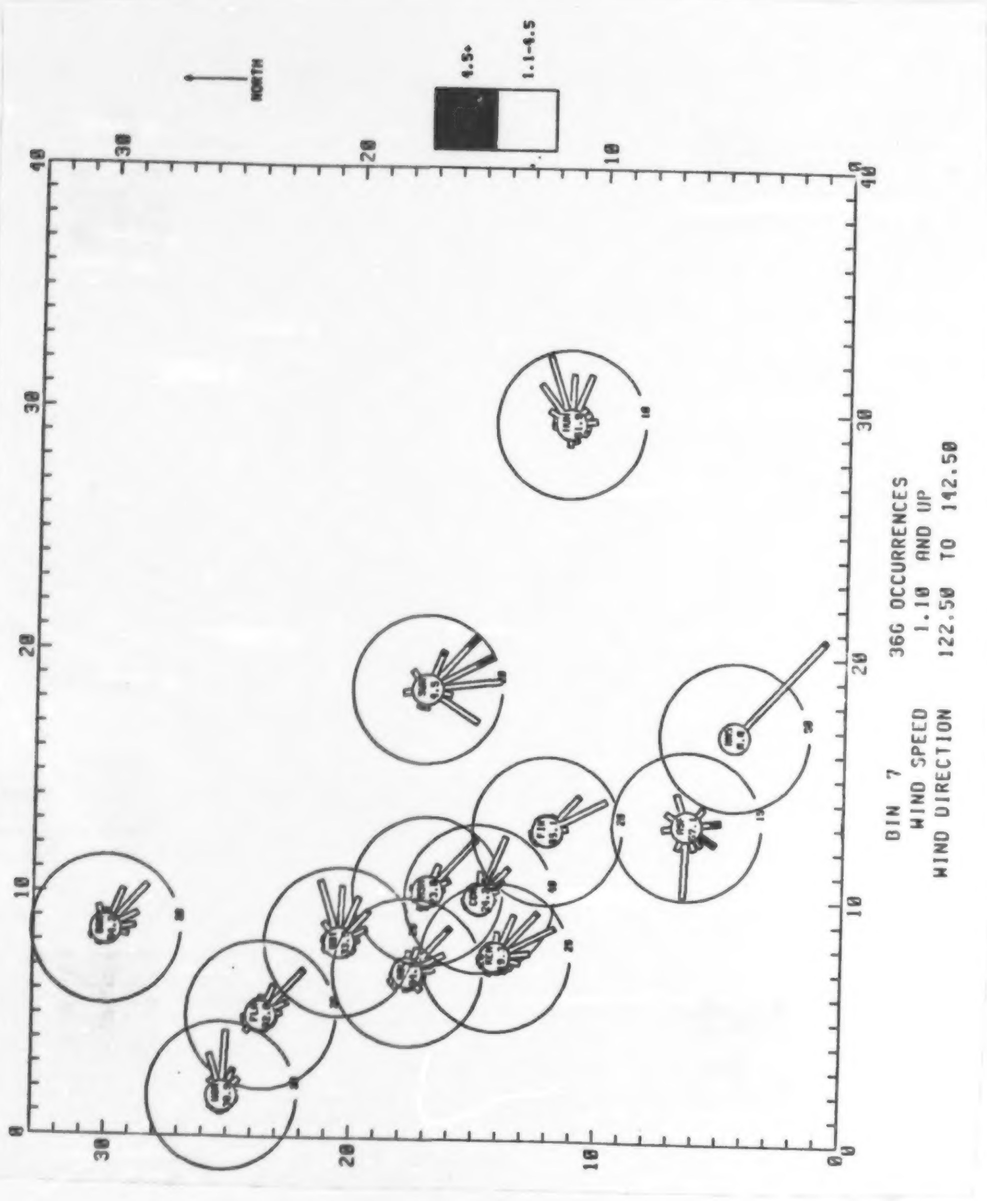
BIN 4 445 OCCURRENCES
WIND SPEED 1.10 AND UP
WIND DIRECTION 62.50 TO 82.50



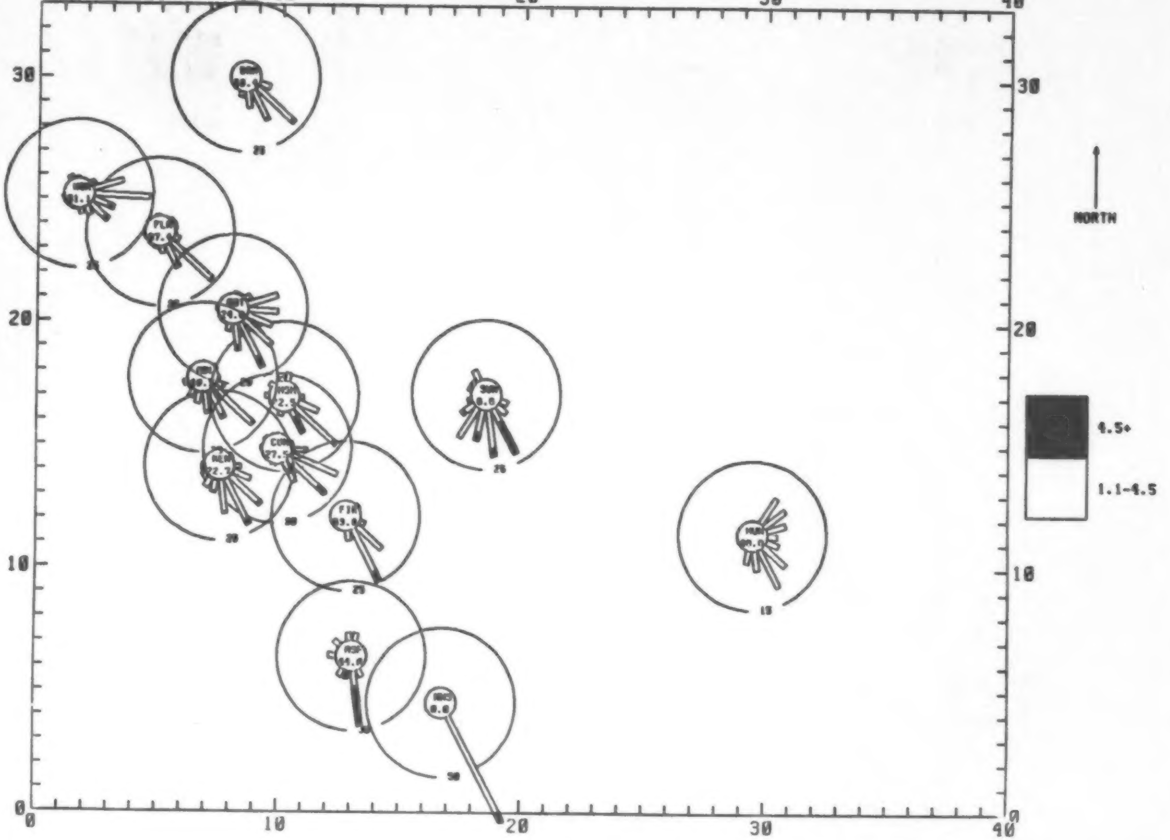
BIN 5 352 OCCURRENCES
WIND SPEED 1.10 AND UP
WIND DIRECTION 82.50 TO 102.50



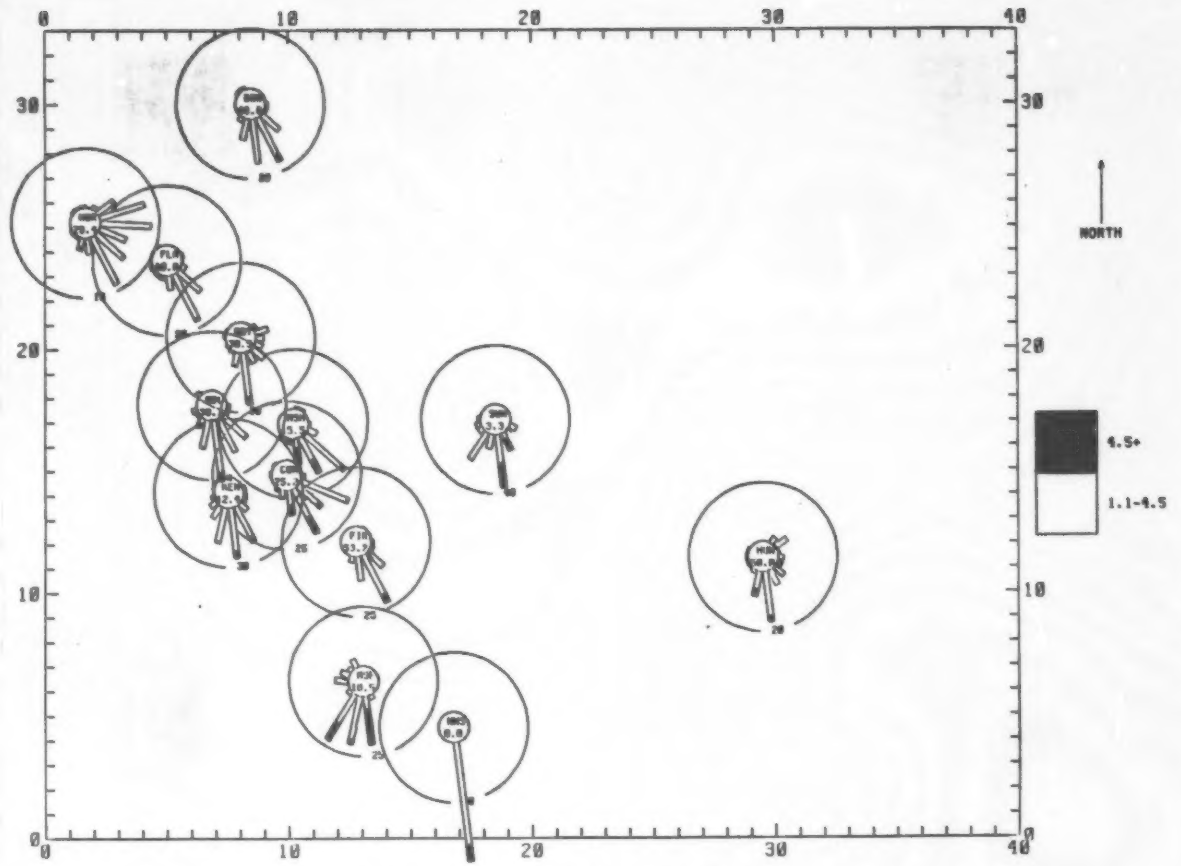
DIN G 440 OCCURRENCES
WIND SPEED 1.10 AND UP
WIND DIRECTION 102.50 TO 122.50



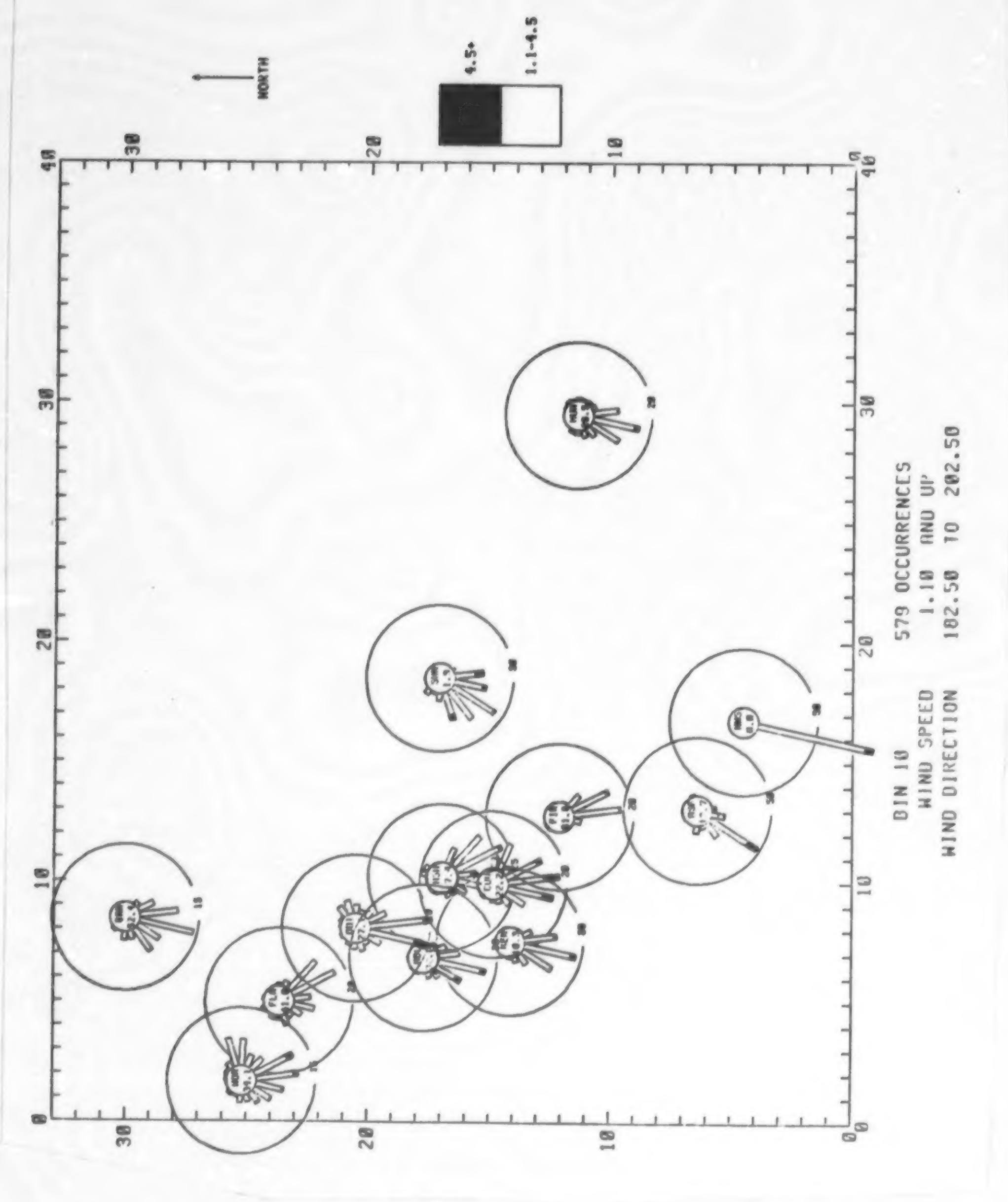
BIN 7 366 OCCURRENCES
WIND SPEED 1.10 AND UP
WIND DIRECTION 122.50 TO 142.50

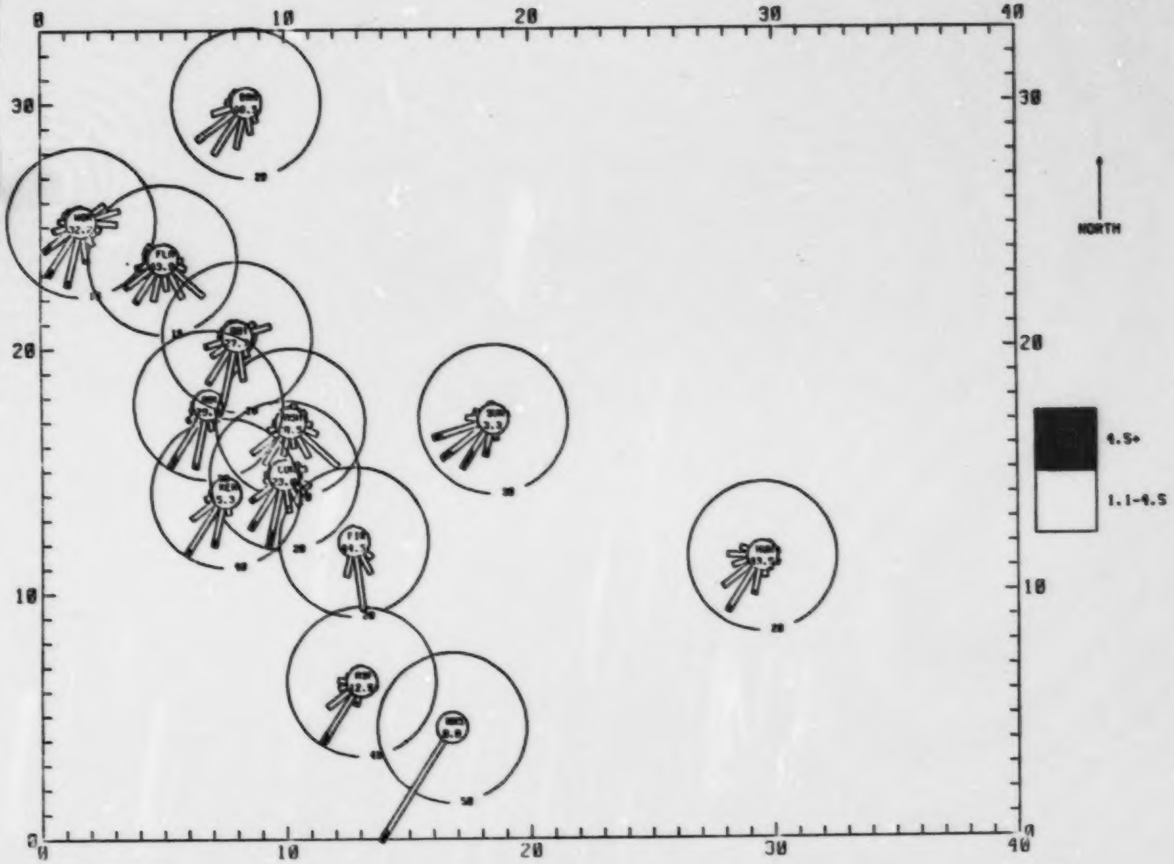


BIN 8 311 OCCURRENCES
WIND SPEED 1.10 AND UP
WIND DIRECTION 142.50 TO 162.50

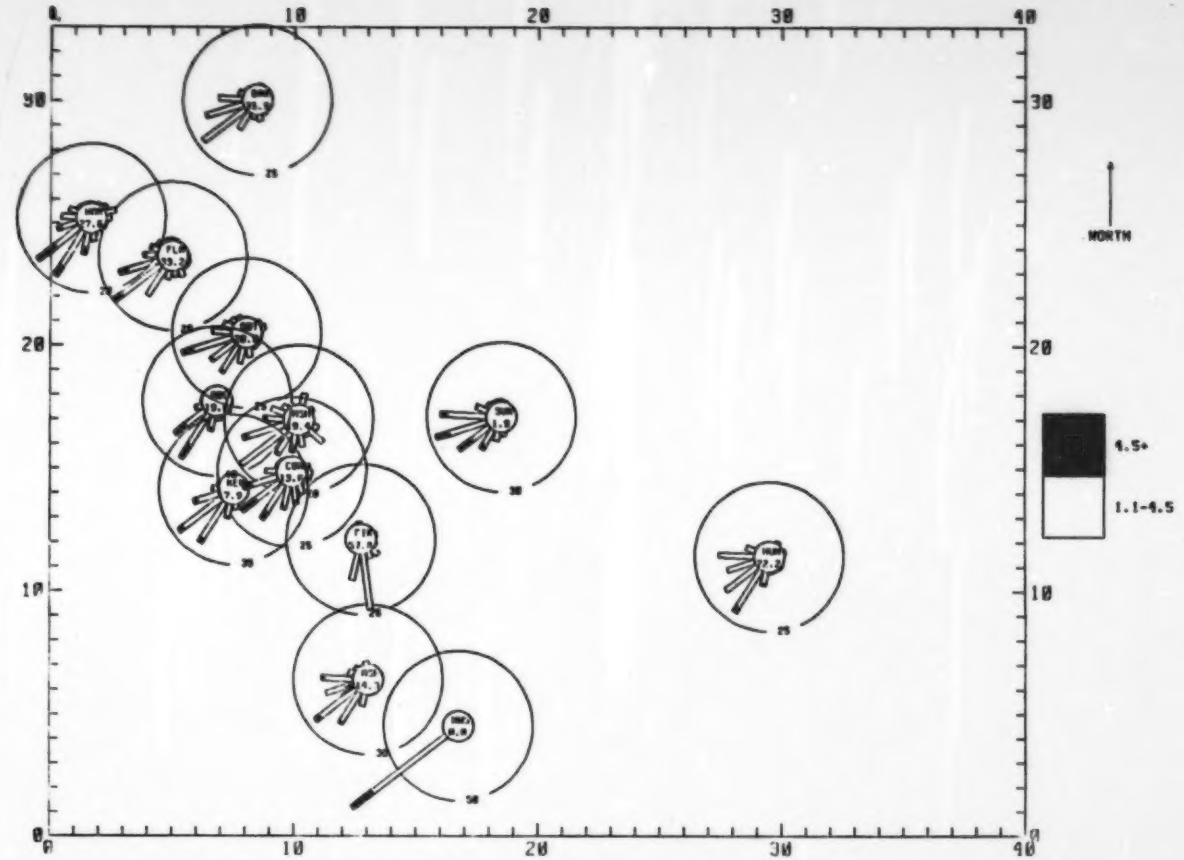


DIN 9 357 OCCURRENCES
WIND SPEED 1.10 AND UP
WIND DIRECTION 162.50 TO 182.50

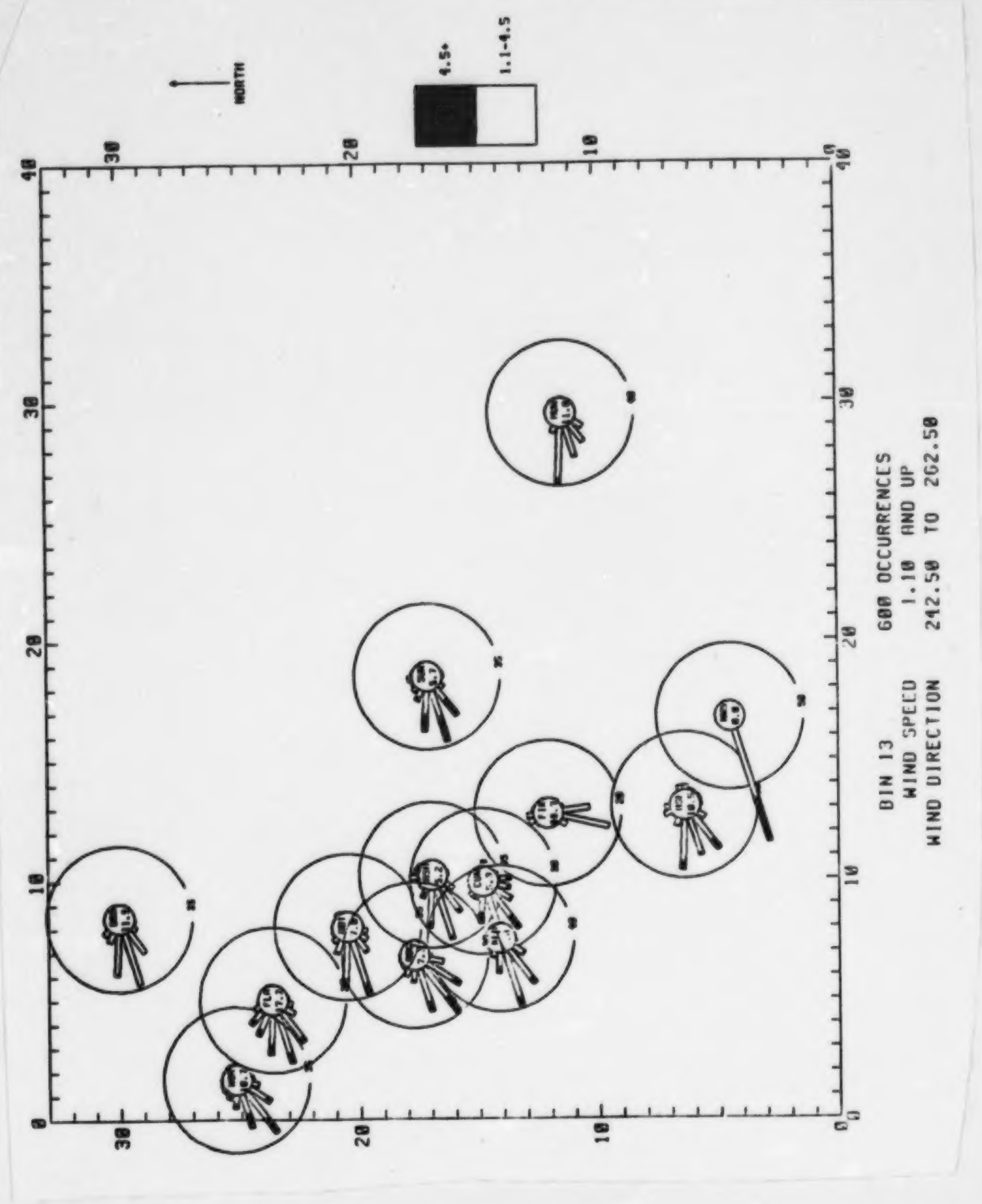

NORTH
4.5+
1.1-4.5
0
10
20
30
40
BIN 10
WIND SPEED
WIND DIRECTION
579 OCCURRENCES
1.10 AND UP
102.50 TO 202.50



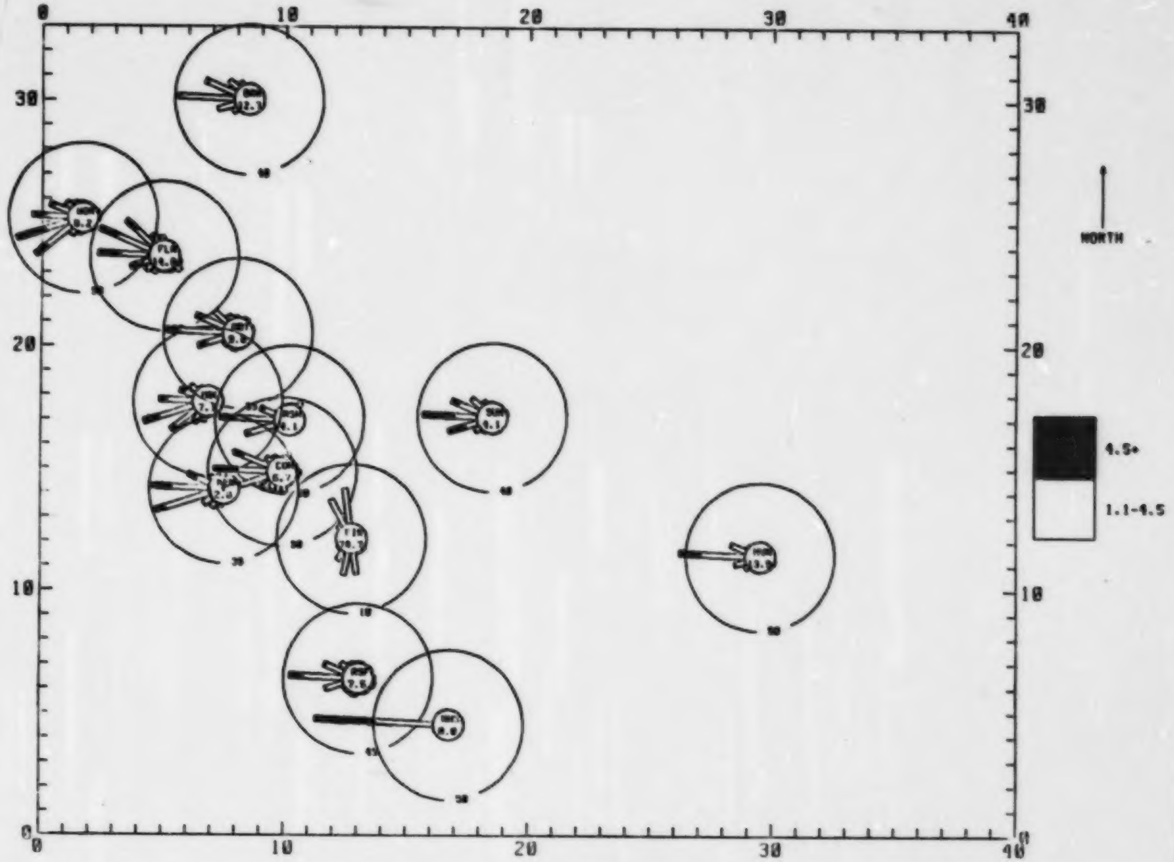
BIN 11 1064 OCCURRENCES
WIND SPEED 1.10 AND UP
WIND DIRECTION 202.50 TO 222.50



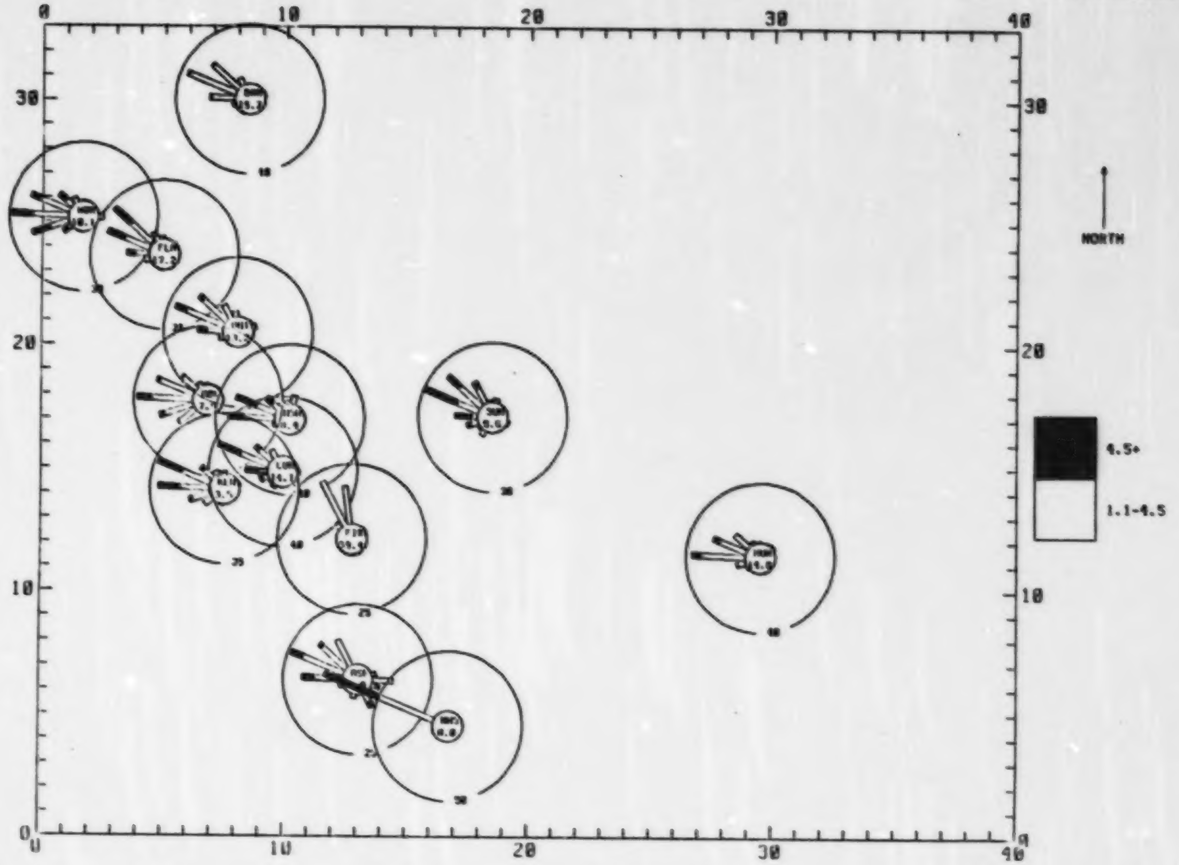
BIN 12 733 OCCURRENCES
WIND SPEED 1.10 AND UP
WIND DIRECTION 222.50 TO 242.50


NORTH
4.5+
1.1-4.5
0
10
20
30
40

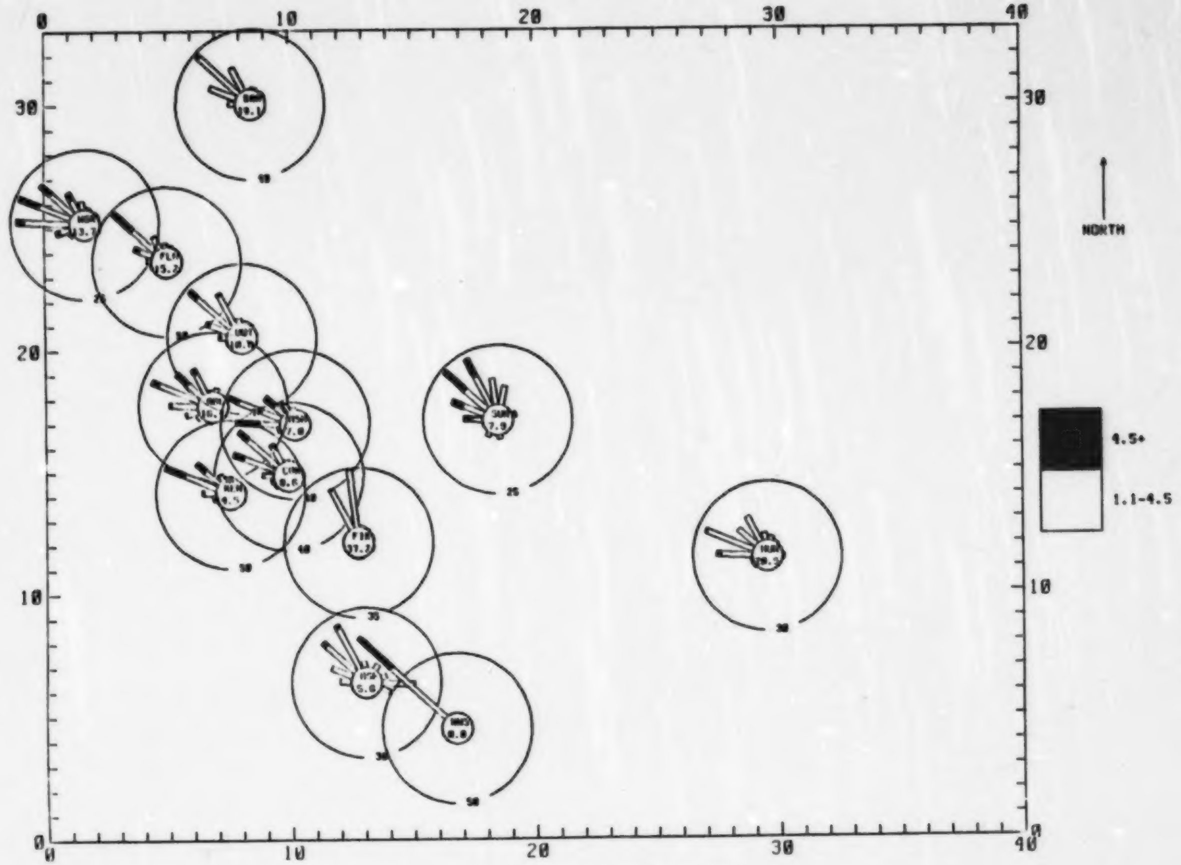
BIN 13 600 OCCURRENCES
WIND SPEED 1.10 AND UP
WIND DIRECTION 242.50 TO 262.50



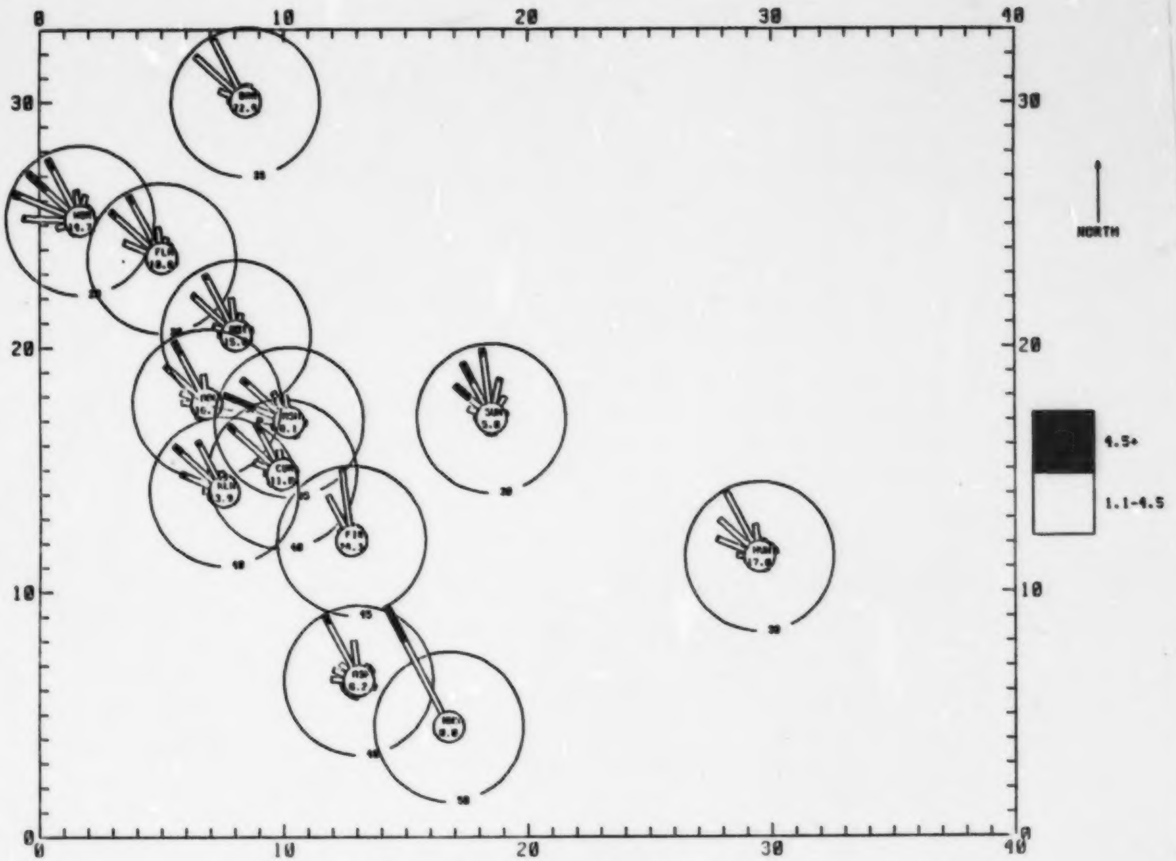
BIN 14 595 OCCURRENCES
WIND SPEED 1.10 AND UP
WIND DIRECTION 262.50 TO 282.50



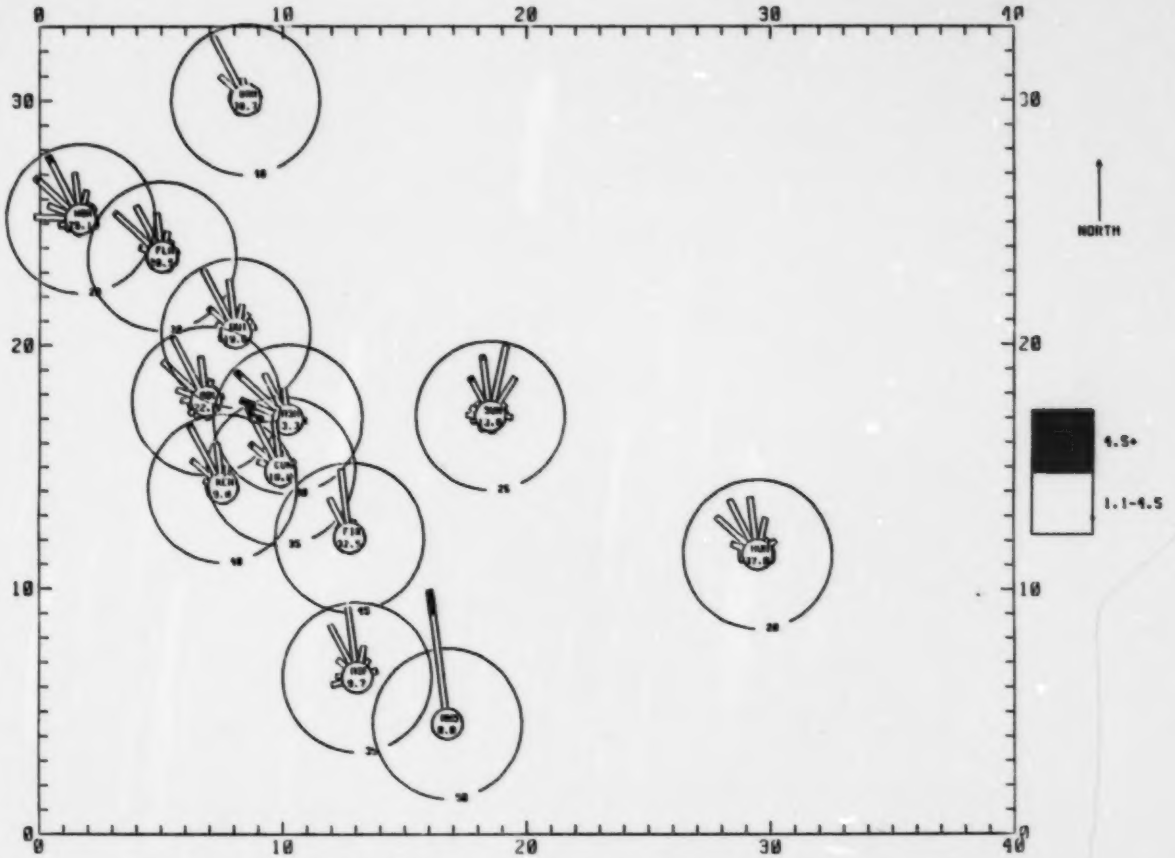
DIN 15 390 OCCURRENCES
WIND SPEED 1.10 AND UP
WIND DIRECTION 202.50 TO 302.50



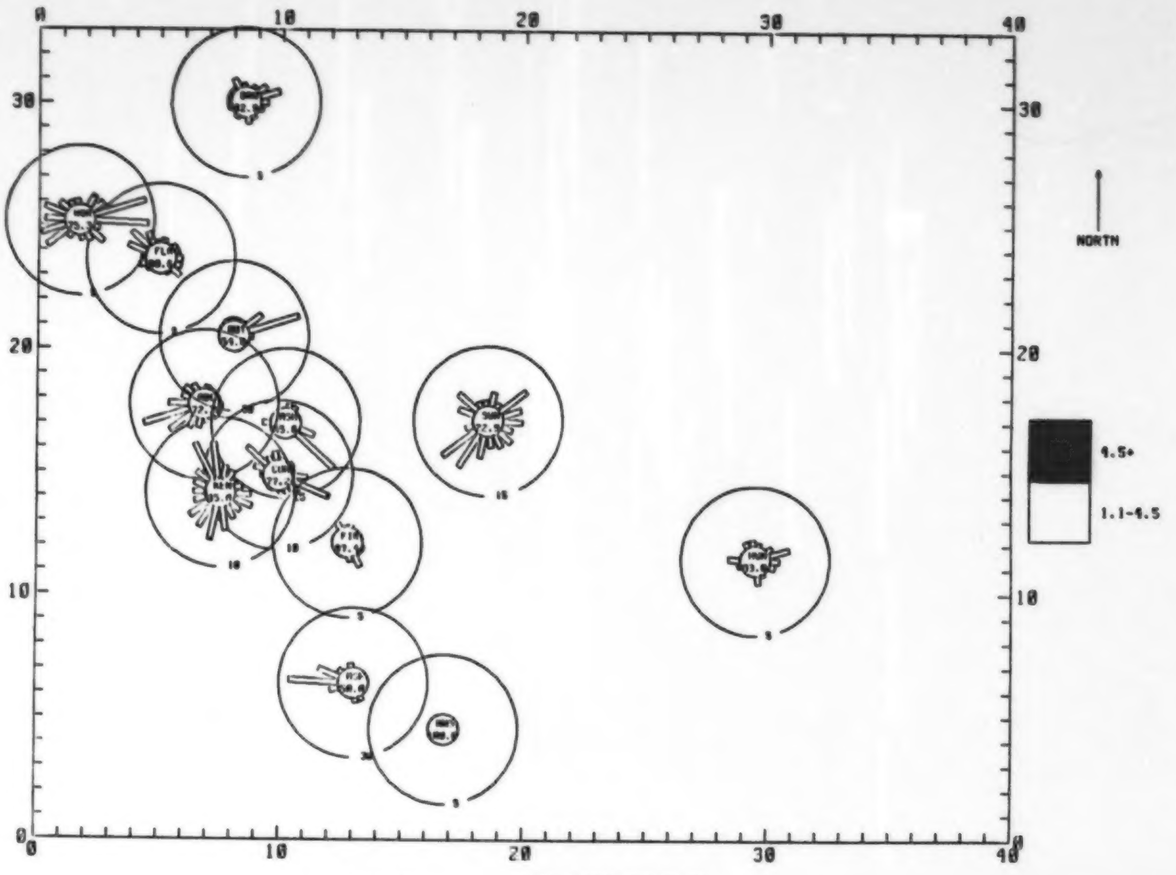
BIN 16 376 OCCURRENCES
WIND SPEED 1.10 AND UP
WIND DIRECTION 302.50 TO 322.50



BIN 17 470 OCCURRENCES
WIND SPEED 1.10 AND UP
WIND DIRECTION 322.50 TO 342.50



BIN 18 421 OCCURRENCES
WIND SPEED 1.10 AND UP
WIND DIRECTION 342.50 AND UP



BIN 19 875 OCCURRENCES
CALM (WIND SPEED LESS THAN 1.1)

APPENDIX D

SUMMARY OF THE REGRESSION OF STATION WIND VELOCITY ON NWS WIND VELOCITY AS STRATIFIED BY NWS WIND DIRECTION

TABLE D-1. REGRESSION RESULTS FOR THE TWELVE NETWORK STATIONS FOR EACH WIND DIRECTION BIN

(a) Station ABC

BIN NO.	WIND DIRECTION (DEGREES)	GAMMA*	ALPHA*	BETA*	SPEED CORRELATION	INTER-QUARTILE RANGE SPEED	INTER-QUARTILE RANGE DIRECTION	COMBINED STANDARD ERROR	NUMBER OF POINTS
1	2.50 TO 22.50	-25.	0.86	-0.81	0.72	1.0	66.	1.0	117
2	22.50 TO 42.50	-27.	0.69	-0.35	0.66	0.8	79.	1.1	150
3	42.50 TO 62.50	-19.	0.81	-0.56	0.75	1.0	54.	1.0	194
4	62.50 TO 82.50	-9.	0.62	-0.12	0.63	0.9	32.	0.9	180
5	82.50 TO 102.50	17.	0.72	-0.60	0.81	0.7	94.	1.0	167
6	102.50 TO 122.50	40.	0.63	-0.36	0.66	0.7	88.	0.8	190
7	122.50 TO 142.50	25.	0.79	-0.65	0.71	0.8	75.	0.9	176
8	142.50 TO 162.50	12.	0.84	-0.71	0.79	0.8	54.	0.8	148
9	162.50 TO 182.50	4.	0.70	-0.40	0.78	0.8	46.	0.8	196
10	182.50 TO 202.50	-0.	0.80	-0.40	0.63	1.1	35.	1.0	332
11	202.50 TO 222.50	-9.	0.92	-0.58	0.56	1.6	27.	1.2	487
12	222.50 TO 242.50	-17.	1.22	-1.13	0.71	1.8	26.	1.3	281
13	242.50 TO 262.50	-13.	1.05	-0.91	0.74	1.7	31.	1.4	247
14	262.50 TO 282.50	-19.	0.55	0.60	0.58	1.4	31.	1.3	269
15	282.50 TO 302.50	-19.	0.54	0.39	0.71	1.0	31.	1.2	214
16	302.50 TO 322.50	-17.	0.70	-0.24	0.73	1.3	36.	1.2	152
17	322.50 TO 342.50	-20.	0.62	0.21	0.68	1.4	37.	1.1	168
18	342.50 AND UP	-36.	0.56	0.18	0.59	1.1	44.	1.0	168
19	CALM CONDITIONS†								

* Predicted wind direction = NWS wind direction + gamma; predicted wind speed = alpha * wind speed + beta.

† The 19th bin (calm conditions) corresponds to NWS wind speeds of less than 1.1 m/s, for which the NWS wind direction is indeterminate.

TABLE D-1. (Continued)

(b) Station ASF

BIN NO.	WIND DIRECTION (DEGREES)	GAMMA*	ALPHA*	BETA*	SPEED CORRELATION	INTER-QUARTILE RANGE SPEED	INTER-QUARTILE RANGE DIRECTION	COMBINED STANDARD ERROR	NUMBER OF POINTS
1	2.50 TO 22.50	-29.	0.42	0.67	0.35	1.0	33	0.9	22
2	22.50 TO 42.50	-11.	0.69	0.18	0.59	1.4	51.	1.0	16
3	42.50 TO 62.50	-47.	0.54	0.05	0.61	0.8	58.	0.9	60
4	62.50 TO 82.50	-68.	0.68	-0.31	0.76	0.8	80.	1.0	48
5	82.50 TO 102.50	-104.	0.63	-0.28	0.63	0.7	81.	1.0	37
6	102.50 TO 122.50	4.	0.21	0.70	0.22	0.9	277.	1.4	34
7	122.50 TO 142.50	13.	0.53	0.12	0.38	0.7	208.	1.7	42
8	142.50 TO 162.50	44.	0.95	-0.77	0.85	1.1	125.	1.6	25
9	162.50 TO 182.50	54.	0.88	0.14	0.81	1.7	92.	2.2	54
10	182.50 TO 202.50	21.	0.67	0.65	0.70	1.8	25.	1.2	63
11	202.50 TO 222.50	17.	0.82	0.09	0.64	1.4	33.	1.1	112
12	222.50 TO 242.50	5.	0.53	0.51	0.51	1.0	46.	1.1	70
13	242.50 TO 262.50	1.	0.63	-0.03	0.68	1.4	35.	1.3	124
14	262.50 TO 282.50	-3.	0.51	0.27	0.63	1.3	26.	1.3	133
15	282.50 TO 302.50	8.	0.48	0.67	0.54	1.3	51.	2.3	59
16	302.50 TO 322.50	40.	0.53	0.49	0.52	1.6	122.	2.2	36
17	322.50 TO 342.50	-13.	0.77	-0.66	0.70	0.9	43.	1.2	48
18	342.50 AND UP	-18.	0.49	0.68	0.63	0.8	33.	1.0	31
19	CALM CONDITIONS†								

* Predicted wind direction = NWS wind direction + gamma;
predicted wind speed = alpha • wind speed + beta.

† The 19th bin (calm conditions) corresponds to NWS wind speeds of less than 1.1 m/s, for which the NWS wind direction is indeterminate.

TABLE D-1. (Continued)

(c) Station ASH

BIN NO.	WIND DIRECTION (DEGREES)	GAMMA*	ALPHA*	BETA*	SPEED CORRELATION	INTER-QUARTILE RANGE		COMBINED STANDARD ERROR	NUMBER OF POINTS
						SPEED	DIRECTION		
1	2.50 TO 22.50	-6.	0.49	0.37	0.37	1.2	109.	1.4	33
2	22.50 TO 42.50	-40.	0.53	0.30	0.50	0.9	83.	1.4	41
3	42.50 TO 62.50	-31.	0.58	-0.12	0.59	0.9	105.	1.2	109
4	62.50 TO 82.50	-9.	0.82	-0.86	0.74	1.2	96.	1.4	95
5	82.50 TO 102.50	3.	0.56	-0.08	0.59	0.8	46.	1.3	63
6	102.50 TO 122.50	2.	1.15	-0.97	0.75	1.1	15.	1.3	78
7	122.50 TO 142.50	-0.	0.93	-0.37	0.72	1.2	11.	1.2	61
8	142.50 TO 162.50	-18.	1.05	-0.64	0.87	1.4	18.	1.2	40
9	162.50 TO 182.50	-30.	0.93	-0.29	0.86	1.3	32.	1.3	84
10	182.50 TO 202.50	-28.	0.68	-0.10	0.82	0.8	36.	1.3	86
11	202.50 TO 222.50	-31.	0.93	-1.01	0.60	0.9	94.	1.6	151
12	222.50 TO 242.50	-9.	0.67	-0.38	0.71	1.0	62.	1.3	103
13	242.50 TO 262.50	8.	0.96	-1.51	0.63	1.1	30.	1.6	153
14	262.50 TO 282.50	8.	0.61	0.15	0.68	1.3	21.	1.3	145
15	282.50 TO 302.50	-0.	1.55	-3.12	0.66	2.4	20.	2.4	83
16	302.50 TO 322.50	-22.	1.27	-1.75	0.84	1.6	23.	1.2	71
17	322.50 TO 342.50	-24.	0.92	-0.37	0.72	1.3	33.	1.2	74
18	342.50 AND UP	-41.	0.73	0.19	0.65	1.2	33.	1.1	60
19	CALM CONDITIONS†								

* Predicted wind direction = NWS wind direction + gamma;
predicted wind speed = alpha • wind speed + beta.

† The 19th bin (calm conditions) corresponds to NWS wind speeds of less than 1.1 m/s, for which the NWS wind direction is indeterminate.

TABLE D-1. (Continued)

(d) Station BAM

BIN NO.	WIND DIRECTION (DEGREES)	GAMMA *	ALPHA *	BETA *	SPEED CORRELATION	INTER-QUARTILE RANGE SPEED	INTER-QUARTILE RANGE DIRECTION	COMBINED STANDARD ERROR	NUMBER OF POINTS
1----------	2.50 TO 22.50	-7.	0.39	-0.07	0.60	0.7	48.	0.7	153
2---------	22.50 TO 42.50	-4.	0.41	-0.09	0.62	0.8	54.	0.7	161
3---------	42.50 TO 62.50	-5.	0.46	-0.09	0.75	0.7	32.	0.6	252
4---------	62.50 TO 82.50	-5.	0.47	-0.04	0.77	0.7	25.	0.5	235
5---------	82.50 TO 102.50	-2.	0.44	0.05	0.65	0.7	49.	0.6	151
6--------	102.50 TO 122.50	-5.	0.57	-0.32	0.65	0.7	58.	0.6	183
7--------	122.50 TO 142.50	2.	0.54	-0.26	0.65	0.7	54.	0.6	155
8--------	142.50 TO 162.50	-0.	0.63	-0.45	0.84	0.6	47.	0.6	129
9--------	162.50 TO 182.50	1.	0.63	-0.48	0.87	0.7	42.	0.7	127
10--------	182.50 TO 202.50	5.	0.46	-0.20	0.81	0.6	49.	0.6	185
11--------	202.50 TO 222.50	1.	0.40	0.05	0.66	0.7	36.	0.6	380
12--------	222.50 TO 242.50	3.	0.42	-0 03	0.65	0.7	33.	0.7	301
13--------	242.50 TO 262.50	5.	0.45	0 08	0.67	0.9	27.	0.7	313
14--------	262.50 TO 282.50	4.	0.53	-0.11	0.75	0.9	25.	0.8	316
15--------	282.50 TO 302.50	-5.	0.49	0.18	0.81	1.0	28.	0.8	184
16--------	302.50 TO 322.50	-3.	0.39	-0.31	0.80	0.8	25.	0.7	157
17--------	322.50 TO 342.50	-12.	0.51	-0.04	0.67	0.9	19.	0.7	223
18--------	342.50 AND UP	-18.	0.51	-0.25	0.69	0.8	18.	0.6	222
19--------	CALM CONDITIONS†								

* Predicted wind direction = NWS wind direction + gamma; predicted wind speed = alpha • wind speed + beta.

† The 19th bin (calm conditions) corresponds to NWS wind speeds of less than 1.1 m/s, for which the NWS wind direction is indeterminate.

TABLE D-1. (Continued)

(e) Station CON

BIN NO.	WIND DIRECTION (DEGREES)	GAMMA *	ALPHA *	BETA *	SPEED CORRELATION	INTER-QUARTILE RANGE SPEED	INTER-QUARTILE RANGE DIRECTION	COMBINED STANDARD ERROR	NUMBER OF POINTS
1	2.50 TO 22.50	-21.	0.69	-0.11	0.55	1.0	49.	1.0	126
2	22.50 TO 42.50	-16.	0.55	0.15	0.52	1.1	48.	1.0	147
3	42.50 TO 62.50	-21.	0.59	0.04	0.62	0.9	49.	0.9	209
4	62.50 TO 82.50	-12.	0.70	-0.30	0.66	0.9	50.	0.9	207
5	82.50 TO 102.50	-4.	0.70	-0.43	0.70	0.8	53.	0.7	150
6	102.50 TO 122.50	1.	0.80	-0.33	0.60	1.0	24.	0.7	190
7	122.50 TO 142.50	-13.	0.78	-0.12	0.65	1.0	27.	1.0	152
8	142.50 TO 162.50	-23	1.03	-0.58	0.76	1.1	31.	1.0	131
9	162.50 TO 182.50	-29.	0.93	-0.48	0.82	1.1	41.	1.1	143
10	182.50 TO 202.50	-23.	0.94	-0.51	0.73	1.0	58.	1.4	203
11	202.50 TO 222.50	-32.	1.28	-1.34	0.71	1.4	68.	1.7	427
12	222.50 TO 242.50	-21.	1.20	-1.28	0.73	1.4	58.	1.7	324
13	242.50 TO 262.50	-18.	0.93	-0.45	0.74	1.2	36.	1.8	321
14	262.50 TO 282.50	-11.	0.83	-0.12	0.65	1.7	35.	1.8	298
15	282.50 TO 302.50	-6.	0.99	-0.62	0.76	1.6	32.	1.5	191
16	302.50 TO 322.50	-8.	1.10	-1.22	0.75	1.2	23.	1.3	174
17	322.50 TO 342.50	-18.	0.90	-0.51	0.65	1.3	24.	1.2	228
18	342.50 AND UP	-23	1.08	-0.99	0.72	1.4	34	1.1	205
19	CALM CONDITIONS†								

* Predicted wind direction = NWS wind direction + gamma; predicted wind speed = alpha × wind speed + beta.

† The 19th bin (calm conditions) corresponds to NWS wind speeds of less than 1.1 m/s, for which the NWS wind direction is indeterminate.

TABLE D-1. (Continued)

(f) Station FIR

BIN NO.	WIND DIRECTION (DEGREES)	GAMMA*	ALPHA*	BETA*	SPEED CORRELATION	INTER-QUARTILE RANGE SPEED	INTER-QUARTILE RANGE DIRECTION	COMBINED STANDARD ERROR	NUMBER OF POINTS
1---------	2.50 TO 22.50	-11.	0.73	-0.56	0.62	1.1	33.	0.8	179
2---------	22.50 TO 42.50	-12.	0.75	-0.75	0.66	1.1	55.	0.8	202
3---------	42.50 TO 62.50	-13.	0.64	-0.68	0.71	0.8	64.	0.7	233
4---------	62.50 TO 82.50	3.	0.48	-0.37	0.66	0.8	99.	0.7	277
5---------	82.50 TO 102.50	15.	0.38	-0.30	0.58	0.8	116.	0.6	194
6--------	102.50 TO 122.50	36.	0.50	-0.50	0.55	0.9	58.	0.6	261
7--------	122.50 TO 142.50	17.	0.83	-1.10	0.71	0.9	52.	0.7	235
8--------	142.50 TO 162.50	4.	0.94	-1.08	0.83	1.0	39.	0.7	169
9--------	162.50 TO 182.50	-3.	0.80	-0.97	0.82	1.0	39.	0.8	201
10--------	182.50 TO 202.50	-9.	0.69	-0.88	0.73	1.0	42.	0.7	327
11--------	202.50 TO 222.50	-18.	0.60	-0.81	0.62	0.9	37.	0.7	612
12--------	222.50 TO 242.50	-29.	0.40	-0.34	0.54	1.0	38.	0.7	412
13--------	242.50 TO 262.50	-29.	0.21	0.04	0.41	0.8	72.	0.8	348
14--------	262.50 TO 282.50	-10.	0.09	0.31	0.23	0.6	139.	0.7	347
15--------	282.50 TO 302.50	7.	0.19	0.28	0.37	1.1	82.	0.9	219
16--------	302.50 TO 322.50	19.	0.50	-0.35	0.61	1.4	19.	0.8	207
17--------	322.50 TO 342.50	8.	0.64	-0.49	0.69	1.1	15.	0.7	209
18--------	342.50 AND UP	-10.	0.77	-0.77	0.74	1.1	24.	0.7	240
19--------	CALM CONDITIONS†								

* Predicted wind direction = NWS wind direction + gamma;
predicted wind speed = alpha × wind speed + beta.

† The 19th bin (calm conditions) corresponds to NWS wind speeds of less than 1.1 m/s, for which the NWS wind direction is indeterminate.

TABLE D-1. (Continued)

(g) Station FLA

BIN NO.	WIND DIRECTION (DEGREES)	GAMMA*	ALPHA*	BETA*	SPEED CORRELATION	INTER-QUARTILE RANGE SPEED	INTER-QUARTILE RANGE DIRECTION	COMBINED STANDARD ERROR	NUMBER OF POINTS
1	2.50 TO 22.50	-18.	0.51	-0.06	0.62	0.8	55.	0.8	156
2	22.50 TO 42.50	-13.	0.65	-0.59	0.67	0.8	67.	0.9	199
3	42.50 TO 62.50	-9.	0.76	-0 81	0.80	0.7	48.	0.8	242
4	62.50 TO 82.50	-1.	0.65	-0.60	0.77	0.9	62.	0.7	219
5	82.50 TO 102.50	-15.	0.62	-0.51	0.71	0.8	50.	0.7	179
6	102.50 TO 122.50	-19.	0.81	-0.91	0.73	0.8	37.	0.7	207
7	122.50 TO 142.50	-16.	0.89	-0.90	0.71	1.1	47.	1.0	198
8	142.50 TO 162.50	-8.	0.91	-0.73	0.71	1.1	43.	0.9	193
9	162.50 TO 182.50	-20.	0.67	-0.23	0.68	1.2	40.	1.0	200
10	182.50 TO 202.50	-29.	0.68	-0.45	0.65	1.1	63.	1.0	331
11	202.50 TO 222.50	-32.	0.73	-0.79	0.63	1.1	88.	1.2	397
12	222.50 TO 242.50	-10.	0.71	-0.48	0.61	1.3	72.	1.4	375
13	242.50 TO 262.50	11.	0.78	-0.46	0.70	1.5	49.	1.4	308
14	262.50 TO 282.50	4.	0.88	-0.54	0.70	1.7	41.	1.7	291
15	282.50 TO 302.50	11.	0.91	-0.47	0.83	1.4	30.	1.2	221
16	302.50 TO 322.50	5.	1.11	-1.34	0.84	1.5	18.	1.1	204
17	322.50 TO 342.50	-6.	0.77	-0.45	0.77	1.5	27.	0.9	215
18	342.50 AND UP	-12.	0.58	-0.05	0.60	1.0	38.	0.9	196
19	CALM CONDITIONS †								

* Predicted wind direction = NWS wind direction + gamma;
predicted wind speed = alpha · wind speed + beta.

† The 19th bin (calm conditions) corresponds to NWS wind speeds of less than 1.1 m/s, for which the NWS wind direction is indeterminate.

TABLE D-1. (Continued)

(b) Station HUN

BIN NO.	WIND DIRECTION (DEGREES)	GAMMA*	ALPHA*	BETA*	SPEED CORRELATION	INTER-QUARTILE RANGE SPEED	INTER-QUARTILE RANGE DIRECTION	COMBINED STANDARD ERROR	NUMBER OF POINTS
1	2.50 TO 22.50	6.	0.46	-0.05	0.60	0.7	47.	0.7	172
2	22.50 TO 42.50	9.	0.51	-0.13	0.73	0.6	39.	0.6	127
3	42.50 TO 62.50	-2.	0.46	0.07	0.70	0.5	36.	0.6	196
4	62.50 TO 82.50	-9.	0.49	-0.02	0.75	0.5	33.	0.5	184
5	82.50 TO 102.50	-20.	0.36	0.26	0.66	0.4	30.	0.5	153
6	102.50 TO 122.50	-37.	0.44	0.00	0.56	0.5	31.	0.5	203
7	122.50 TO 142.50	-46.	0.49	-0.11	0.60	0.5	44.	0.7	168
8	142.50 TO 162.50	-48.	0.64	-0.38	0.79	0.9	84.	1.0	121
9	162.50 TO 182.50	-42.	0.85	-0.86	0.81	1.0	114.	1.2	166
10	182.50 TO 202.50	-19.	0.78	-0.74	0.71	1.2	104.	1.1	281
11	202.50 TO 222.50	-6.	0.86	-0.98	0.67	1.2	80.	1.0	313
12	222.50 TO 242.50	11.	0.76	-0.44	0.73	1.1	52.	1.1	293
13	242.50 TO 262.50	6.	0.63	0.02	0.73	0.9	30.	0.9	263
14	262.50 TO 282.50	3	0.78	-0.57	0.85	1.1	17.	0.9	259
15	282.50 TO 302.50	-1.	0.81	-0.66	0.87	1.0	30.	0.9	142
16	302.50 TO 322.50	2.	0.69	-0.44	0.78	1.0	43.	1.0	127
17	322.50 TO 342.50	-5	0.56	-0.15	0.69	0.8	34	0.8	163
18	342.50 AND UP	10.	0.47	-0.10	0.68	0.8	69.	0.8	162
19	CALM CONDITIONS †								

* Predicted wind direction = NWS wind direction + gamma;
predicted wind speed = alpha × wind speed + beta.

† The 19th bin (calm conditions) corresponds to NWS wind speeds of less than 1.1 m/s, for which the NWS wind direction is indeterminate.

TABLE D-1. (Continued)

(i) Station KEN

BIN NO.	WIND DIRECTION (DEGREES)	GAMMA*	ALPHA*	BETA*	SPEED CORRELATION	INTER-QUARTILE RANGE SPEED	INTER-QUARTILE RANGE DIRECTION	COMBINED STANDARD ERROR	NUMBER OF POINTS
1	2.50 TO 22.50	-11.	0.75	0.16	0.67	1.0	40.	1.0	222
2	22.50 TO 42.50	-10.	0.83	-0.03	0.73	1.1	42.	1.1	233
3	42.50 TO 62.50	-6.	0.78	0.18	0.76	1.1	37.	1.1	333
4	62.50 TO 82.50	-6.	0.81	0.05	0.77	1.1	35.	1.0	320
5	82.50 TO 102.50	-3.	0.80	-0.02	0.74	1.2	40.	1.0	277
6	102.50 TO 122.50	4.	0.82	0.11	0.61	1.2	35.	0.9	341
7	122.50 TO 142.50	5.	0.74	0.30	0.61	1.1	48.	1.2	264
8	142.50 TO 162.50	-1.	0.83	-0.05	0.74	1.3	44.	1.0	216
9	162.50 TO 182.50	2.	0.77	0.31	0.76	1.2	37.	1.1	259
10	182.50 TO 202.50	3.	0.66	0.71	0.62	1.3	30.	1.1	446
11	202.50 TO 222.50	-1.	0.69	0.81	0.60	1.3	24.	1.0	791
12	222.50 TO 242.50	-6.	0.61	0.82	0.61	1.2	28.	1.1	521
13	242.50 TO 262.50	-4.	0.62	0.75	0.71	1.1	25.	1.1	457
14	262.50 TO 282.50	-9.	0.70	0.51	0.77	1.2	25.	1.1	433
15	282.50 TO 302.50	-13.	0.76	0.61	0.81	1.3	27.	1.3	287
16	302.50 TO 322.50	-13.	0.95	-0.24	0.83	1.2	22.	1.1	266
17	322.50 TO 342.50	-18.	0.76	0.27	0.79	1.0	25.	1.0	309
18	342.50 AND UP	-17.	0.62	0.57	0.65	1.0	26.	0.9	277
19	CALM CONDITIONS †								

* Predicted wind direction = NWS wind direction + gamma; predicted wind speed = alpha · wind speed + beta.

† The 19^{th} bin (calm conditions) corresponds to NWS wind speeds of less than 1.1 m/s, for which the NWS wind direction is indeterminate.

TABLE D-1. (Continued)

(j) Station ODT

BIN NO.	WIND DIRECTION (DEGREES)	GAMMA*	ALPHA*	BETA*	SPEED CORRELATION	INTER-QUARTILE RANGE SPEED	INTER-QUARTILE RANGE DIRECTION	COMBINED STANDARD ERROR	NUMBER OF POINTS
1	2.50 TO 22.50	0.	0.56	0.21	0.60	0.9	51.	1.0	196
2	22.50 TO 42.50	-5.	0.55	0.10	0.63	0.9	53.	0.9	216
3	42.50 TO 62.50	-8.	0.53	0.25	0.67	1.1	41.	0.9	281
4	62.50 TO 82.50	-9.	0.44	0.33	0.60	0.8	30.	0.7	282
5	82.50 TO 102.50	-10.	0.42	0.37	0.54	0.7	32.	0.7	221
6	102.50 TO 122.50	-24.	0.45	0.31	0.47	0.8	33.	0.8	298
7	122.50 TO 142.50	-36.	0.66	-0.09	0.64	0.8	43.	0.9	251
8	142.50 TO 162.50	-35.	0.85	-0.34	0.76	0.9	67.	1.1	199
9	162.50 TO 182.50	-37.	0.73	-0.13	0.75	1.2	85.	1.3	226
10	182.50 TO 202.50	-39.	0.74	-0.18	0.72	1.0	104.	1.4	380
11	202.50 TO 222.50	-40.	0.79	-0.42	0.68	1.2	110.	1.5	693
12	222.50 TO 242.50	-12.	0.82	-0.51	0.70	1.2	64.	1.4	464
13	242.50 TO 262.50	12.	0.68	0.07	0.77	1.1	26.	1.1	416
14	262.50 TO 282.50	10.	0.70	-0.13	0.76	1.3	35.	1.2	399
15	282.50 TO 302.50	21.	0.65	0.20	0.80	1.2	39.	1.2	265
16	302.50 TO 322.50	9.	0.73	-0.23	0.80	1.1	24.	1.0	241
17	322.50 TO 342.50	2.	0.65	-0.07	0.74	1.2	31.	0.9	320
18	342.50 AND UP	-1.	0.66	-0.10	0.71	1.0	38.	0.9	280
19	CALM CONDITIONS †								

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* Predicted wind direction = NWS wind direction + gamma; predicted wind speed = alpha • wind speed + beta.

† The 19th bin (calm conditions) corresponds to NWS wind speeds of less than 1.1 m/s, for which the NWS wind direction is indeterminate.

TABLE D-1. (Continued)

(k) Station SUN

BIN NO.	WIND DIRECTION (DEGREES)	GAMMA*	ALPHA*	BETA*	SPEED CORRELATION	INTER-QUARTILE RANGE SPEED	INTER-QUARTILE RANGE DIRECTION	COMBINED STANDARD ERROR	NUMBER OF POINTS
1----------	2.50 TO 22.50	21.	0.37	1.20	0 33	1.0	44.	1 3	66
2----------	22.50 TO 42.50	16.	0.36	1.31	0.33	1.0	54.	1.6	54
3----------	42.50 TO 62.50	15.	C.38	1.59	0.32	1.5	46.	1.4	103
4----------	62.50 TO 82.50	17.	0.33	1.59	0.31	1.4	37.	1.5	79
5----------	82.50 TO 102.50	25.	0.16	2.29	0 11	1.4	44.	1.6	64
6---------	102.50 TO 122.50	23.	1.23	0.00	0.59	1.5	36.	1.5	104
7---------	122.50 TO 142.50	27.	0.97	0.63	0.58	1.1	51.	1.7	66
8---------	142.50 TO 162.50	38.	1.00	0.41	0.77	1.9	62.	2 0	61
9---------	162.50 TO 182.50	12.	1.04	0.27	0.82	1 9	41.	1.7	61
10--------	182.50 TO 202.50	26.	0.57	1.40	0 63	1.4	46.	1.4	103
11--------	202.50 TO 222.50	19.	0.56	1.63	0 43	1.7	41.	1.4	213
12--------	222.50 TO 242.50	20.	0.56	1.37	0 48	1.7	39.	1.5	160
13--------	242.50 TO 262.50	9.	0.81	0.49	0.65	1.7	32.	1.5	137
14--------	262.50 TO 282.50	3.	0.89	0.04	0.78	1.8	30.	1.5	169
15--------	282.50 TO 302.50	8.	0.89	−0.03	0.73	1.6	39.	1.6	104
16--------	302.50 TO 322.50	4.	0.71	0.47	0.65	1.3	42.	1.5	63
17--------	322.50 TO 342.50	5.	0.70	0.65	0 54	1.3	41.	1.4	101
18--------	342.50 AND UP	5.	0.38	1.14	0 38	1.4	36.	1.3	109
19--------	CALM CONDITIONS†								

* Predicted wind direction = NWS wind direction + gamma;
predicted wind speed = alpha • wind speed + beta.

† The 19th bin (calm conditions) corresponds to NWS wind speeds of less than 1.1 m/s, for which the NWS wind direction is indeterminate.

TABLE D-1. (Continued)

(1) Station WOR

BIN NO.	WIND DIRECTION (DEGREES)	GAMMA*	ALPHA*	BETA*	SPEED CORRELATION	INTER-QUARTILE RANGE SPEED	INTER-QUARTILE RANGE DIRECTION	COMBINED STANDARD ERROR	NUMBER OF POINTS
1	2.50 TO 22.50	-28.	0.62	0.01	0.58	1.2	86.	1.2	131
2	22.50 TO 42.50	-26.	0.71	-0.21	0.61	1.4	91.	1.3	166
3	42.50 TO 62.50	-17.	0.90	-0.81	0.76	1.3	60.	1.2	241
4	62.50 TO 82.50	-15.	0.91	-0.85	0.71	1.3	51.	1.1	234
5	82.50 TO 102.50	-14.	0.89	-0.65	0.76	1.2	38.	1.1	175
6	102.50 TO 122.50	-20.	0.87	-0.52	0.61	1.2	29.	0.9	218
7	122.50 TO 142.50	-24.	0.66	-0.11	0.56	1.1	40.	1.0	193
8	142.50 TO 162.50	-37.	0.67	-0.01	0.63	1.2	45.	1.1	161
9	162.50 TO 182.50	-46.	0.48	0.17	0.64	1.1	73.	1.1	194
10	182.50 TO 202.50	-42.	0.63	-0.24	0.60	1.1	94.	1.3	279
11	202.50 TO 222.50	-44.	0.87	-0.70	0.61	1.3	127.	1.7	469
12	222.50 TO 242.50	-24.	1.05	-1.21	0.70	1.5	69.	1.6	377
13	242.50 TO 262.50	-11.	1.01	-1.07	0.74	1.7	33.	1.5	354
14	262.50 TO 282.50	-11.	0.88	-0.51	0.72	1.7	36.	1.5	368
15	282.50 TO 302.50	-4.	0.85	-0.22	0.78	1.5	35.	1.6	247
16	302.50 TO 322.50	-13.	0.91	-0.81	0.77	1.6	40.	1.4	226
17	322.50 TO 342.50	-23.	0.89	-0.67	0.76	1.4	43.	1.2	251
18	342.50 AND UP	-33.	0.68	-0.14	0.59	1.2	39.	1.1	191
19	CALM CONDITIONS†								

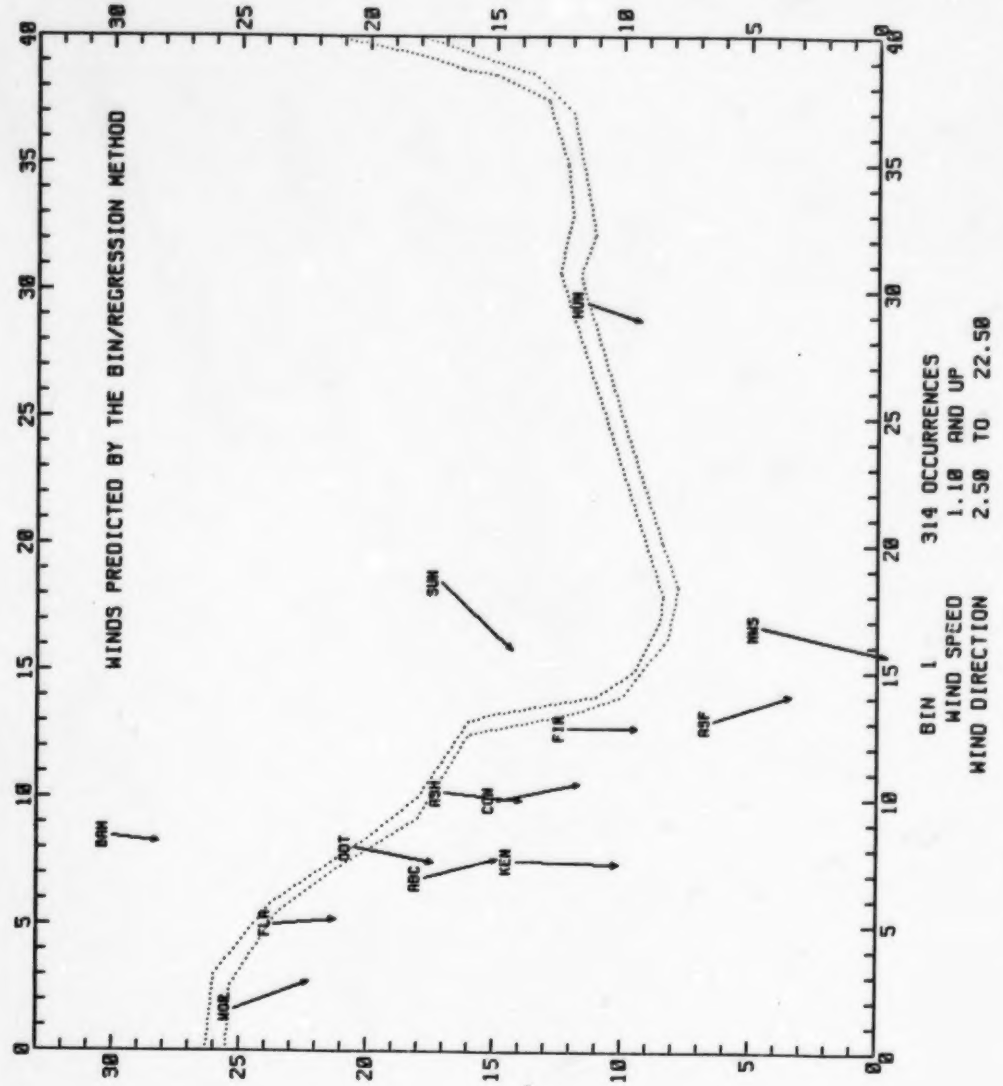
---

* Predicted wind direction = NWS wind direction + gamma;
predicted wind speed = alpha * wind speed + beta.

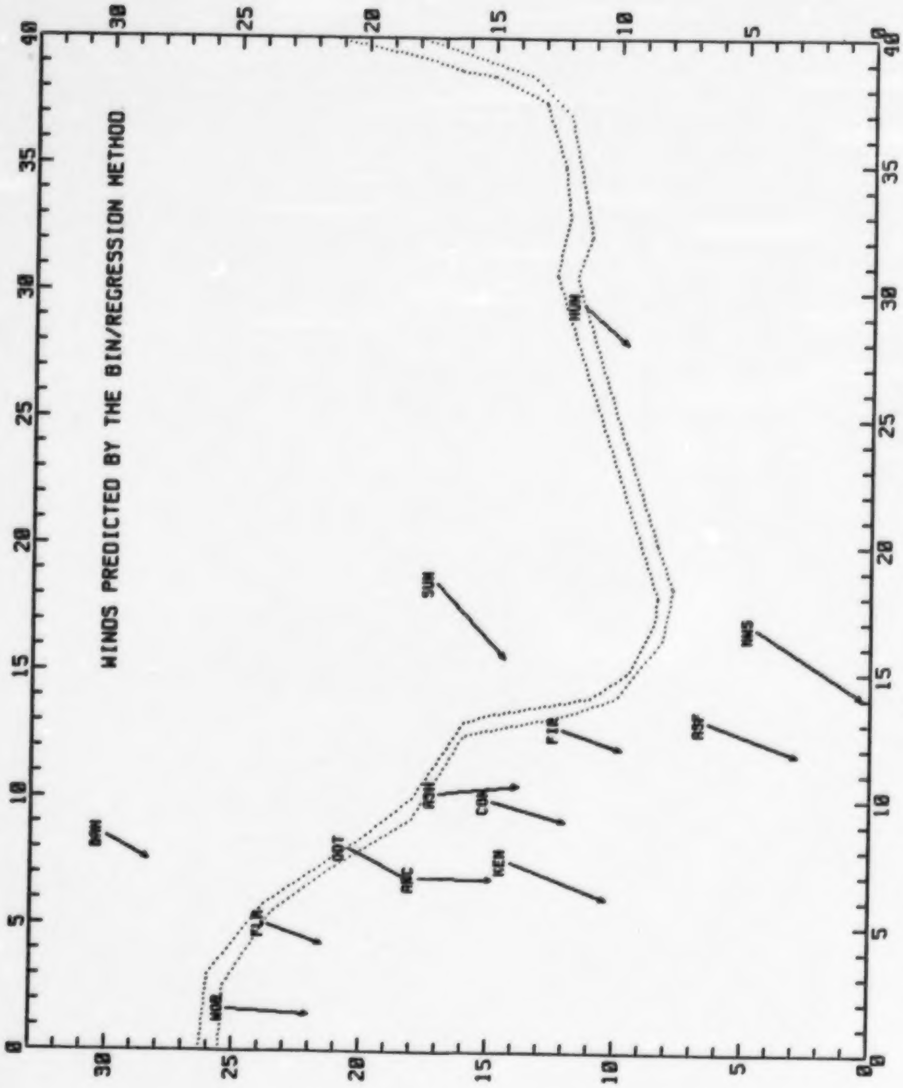
† The 19th bin (calm conditions) corresponds to NWS wind speeds of less than 1.1 m/s, for which the NWS wind direction is indeterminate.

APPENDIX E

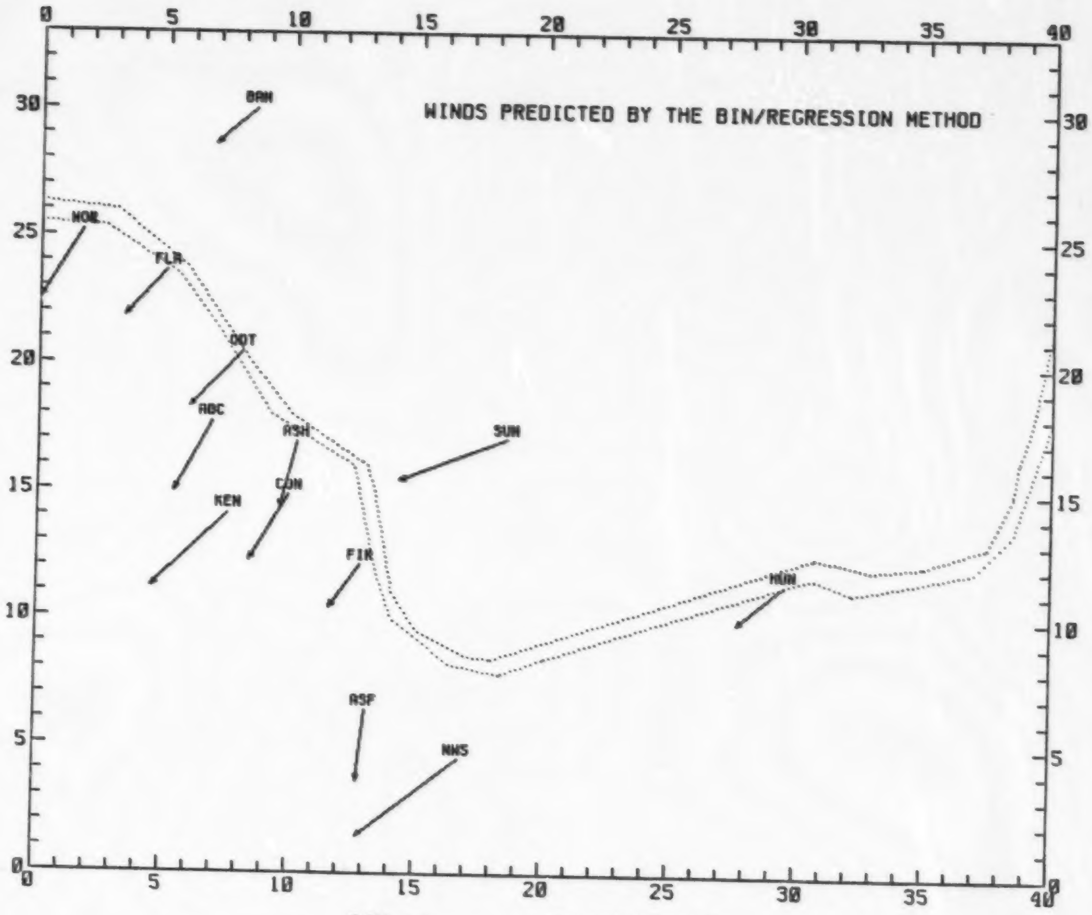
STATION WIND VECTORS PREDICTED USING A SAMPLE NWS WIND VECTOR IN EACH OF THE 18 STRATIFIED NWS WIND DIRECTIONS


WINDS PREDICTED BY THE BIN/REGRESSION METHOD
0
5
10
15
20
25
30
35
40
0
5
10
15
20
25
30
BRN
WOR
FLR
DOT
ABC
ASH
COM
KEN
FIR
SUN
ASF
NWS
WOM
BIN 1
WIND SPEED
WIND DIRECTION
314 OCCURRENCES
1.10 AND UP
2.50 TO 22.50

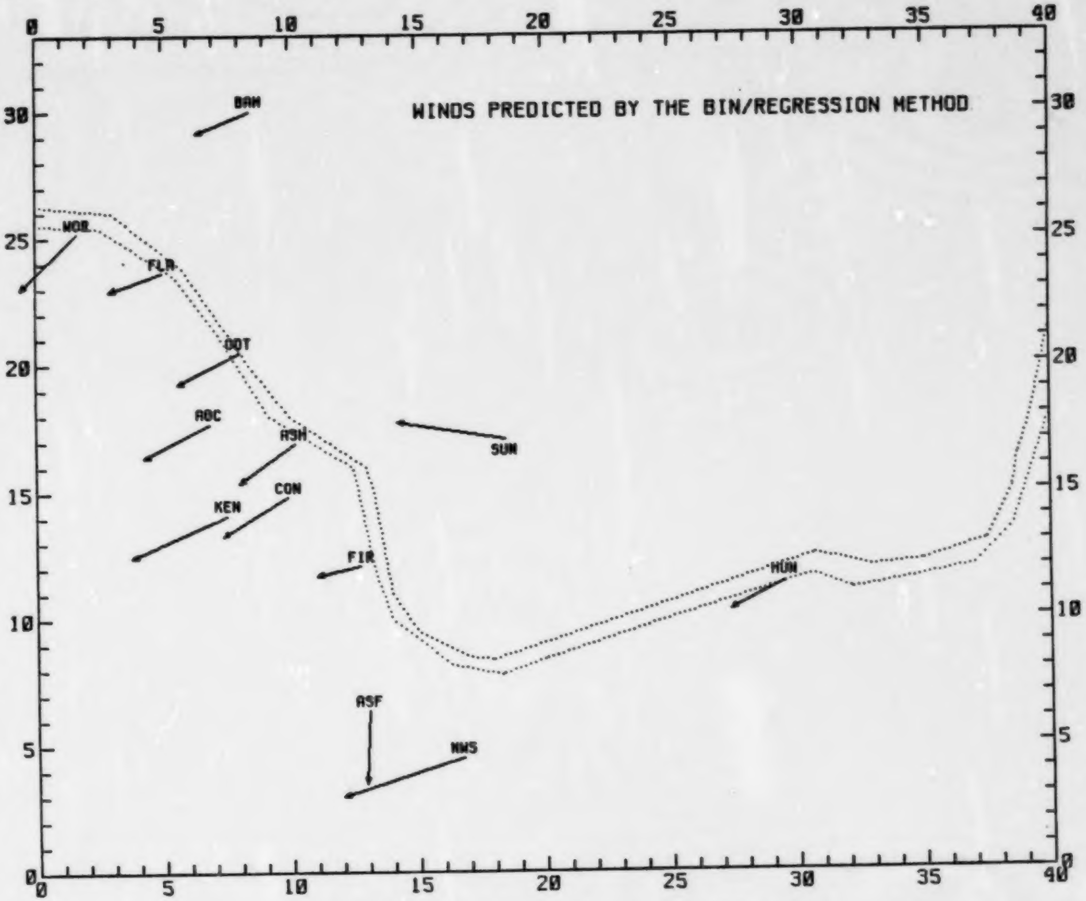
WINDS PREDICTED BY THE BIN/REGRESSION METHOD



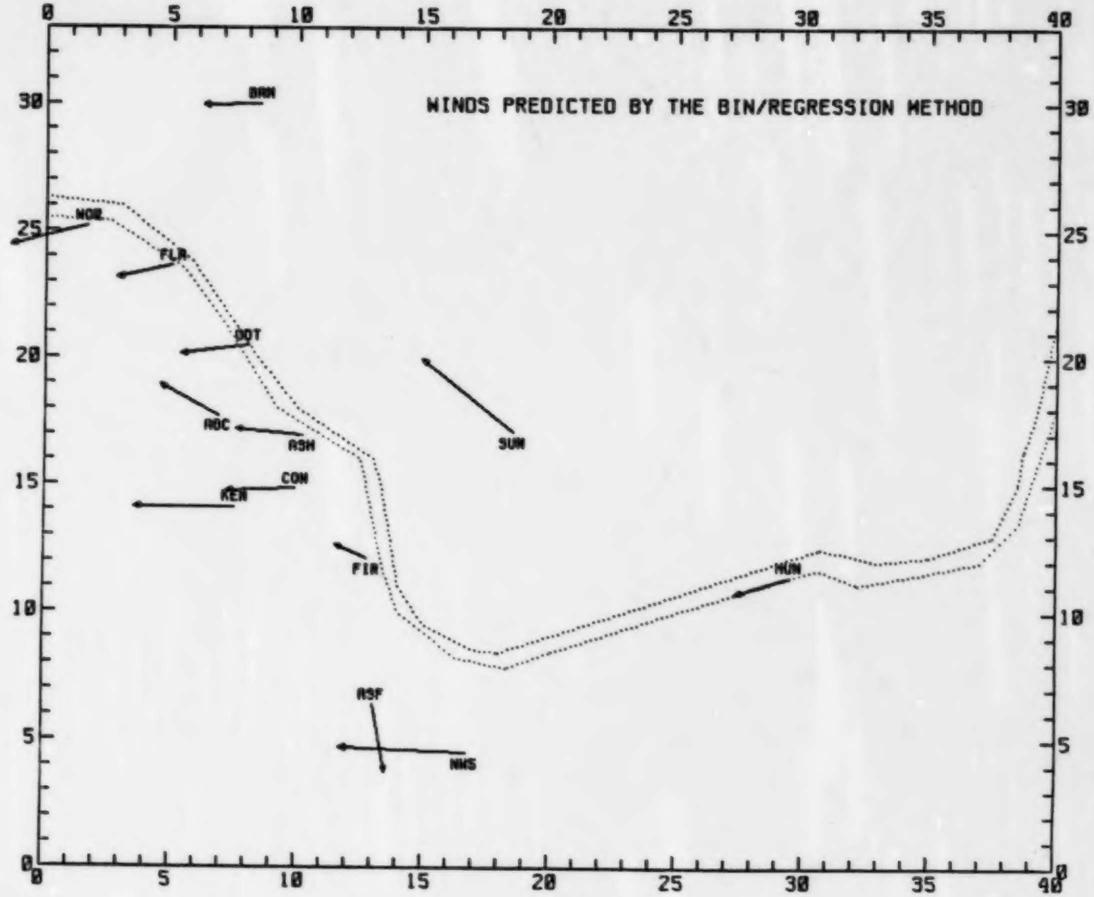
BIN 2 324 OCCURRENCES
WIND SPEED 1.10 AND UP
WIND DIRECTION 22.50 TO 42.50



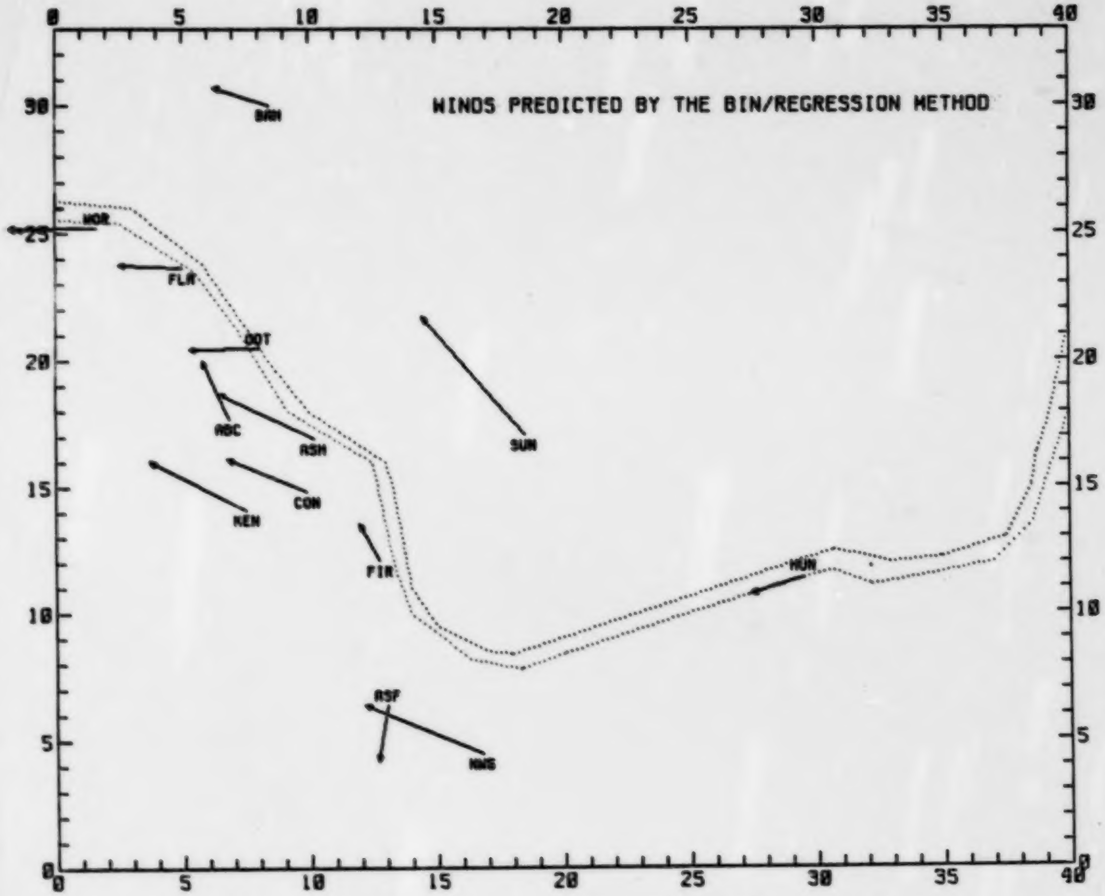
BIN 3 438 OCCURRENCES
WIND SPEED 1.10 AND UP
WIND DIRECTION 42.50 TO 62.50



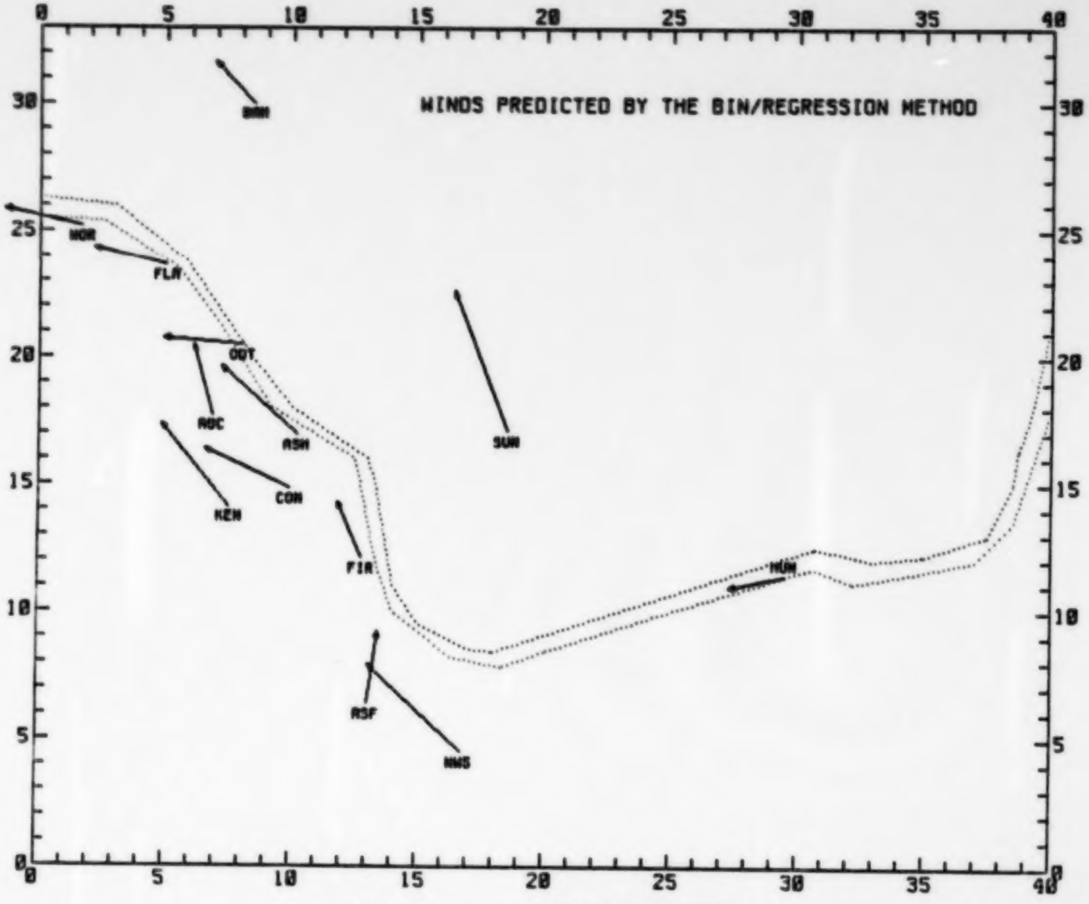
BIN 4 445 OCCURRENCES
WIND SPEED 1.10 AND UP
WIND DIRECTION 62.50 TO 82.50



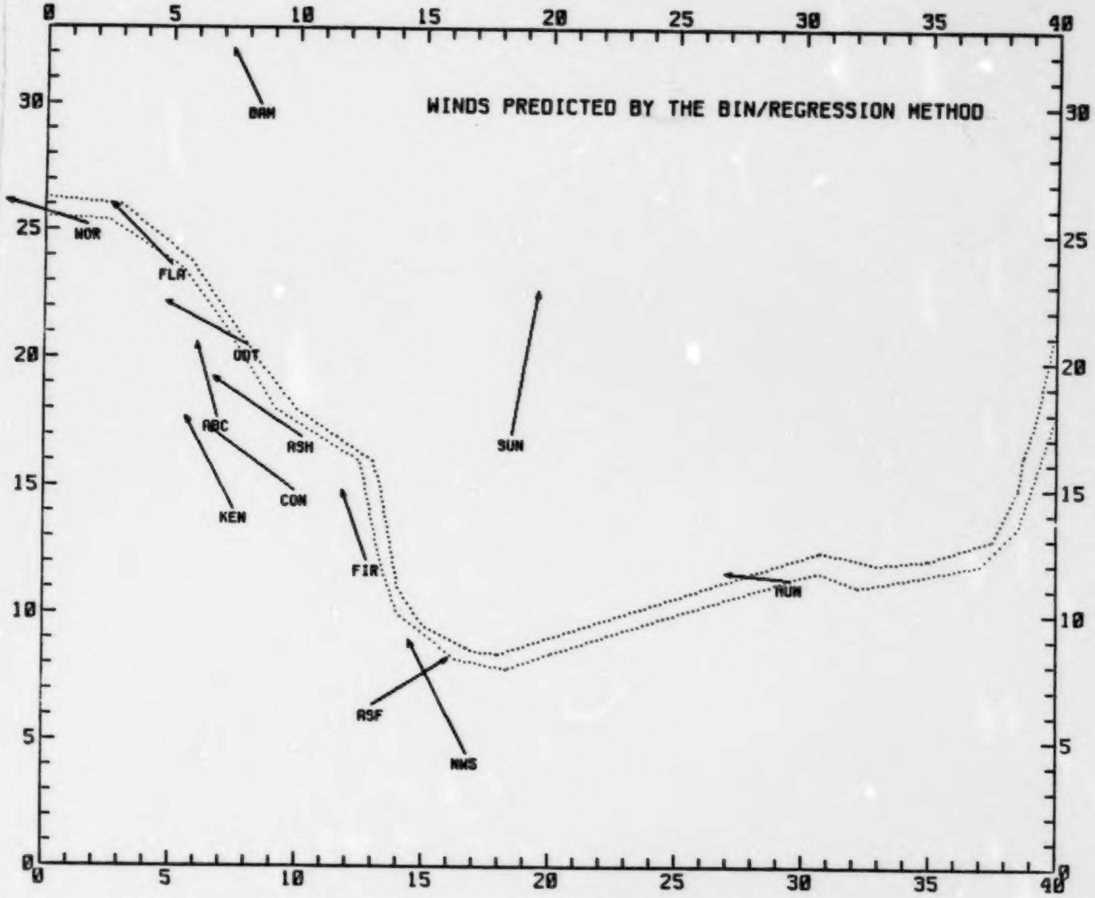
BIN 5 352 OCCURRENCES
WIND SPEED 1.10 AND UP
WIND DIRECTION 82.50 TO 102.50



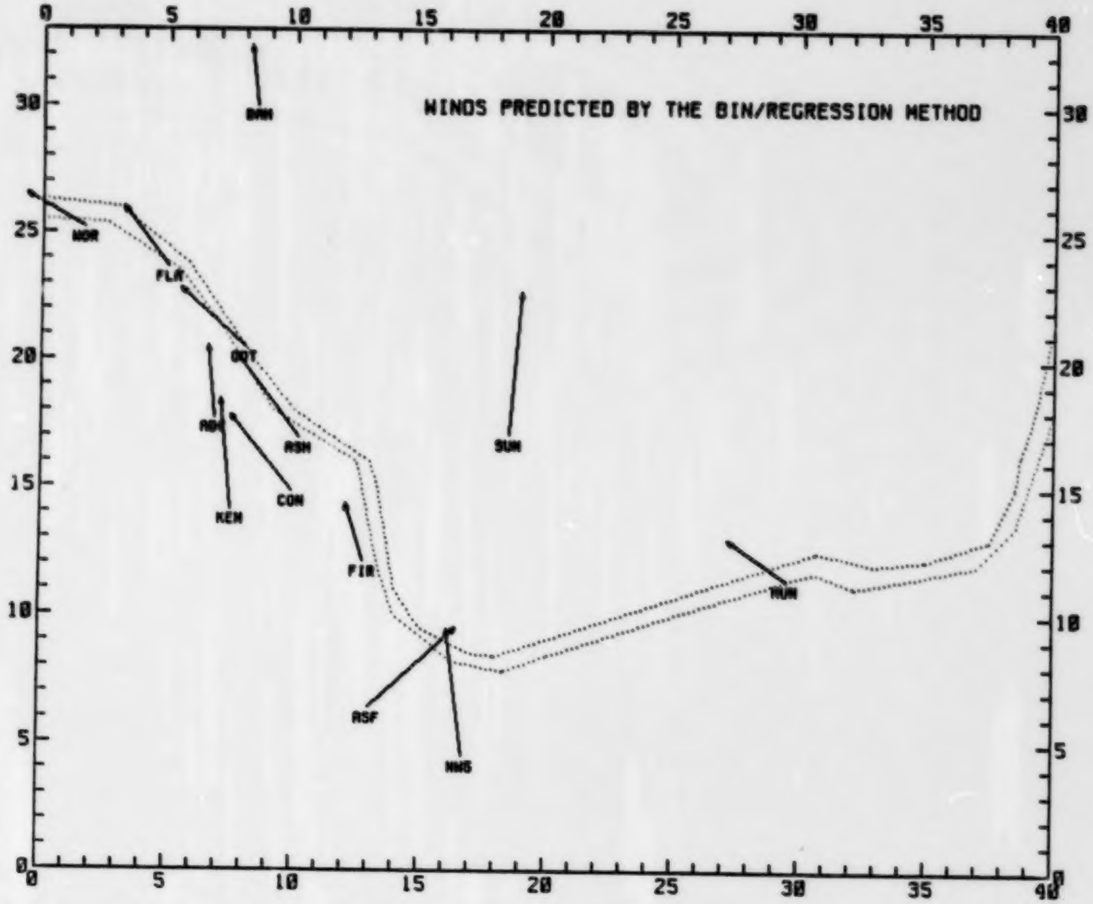
BIN 6 440 OCCURRENCES
WIND SPEED 1.10 AND UP
WIND DIRECTION 102.50 TO 122.50



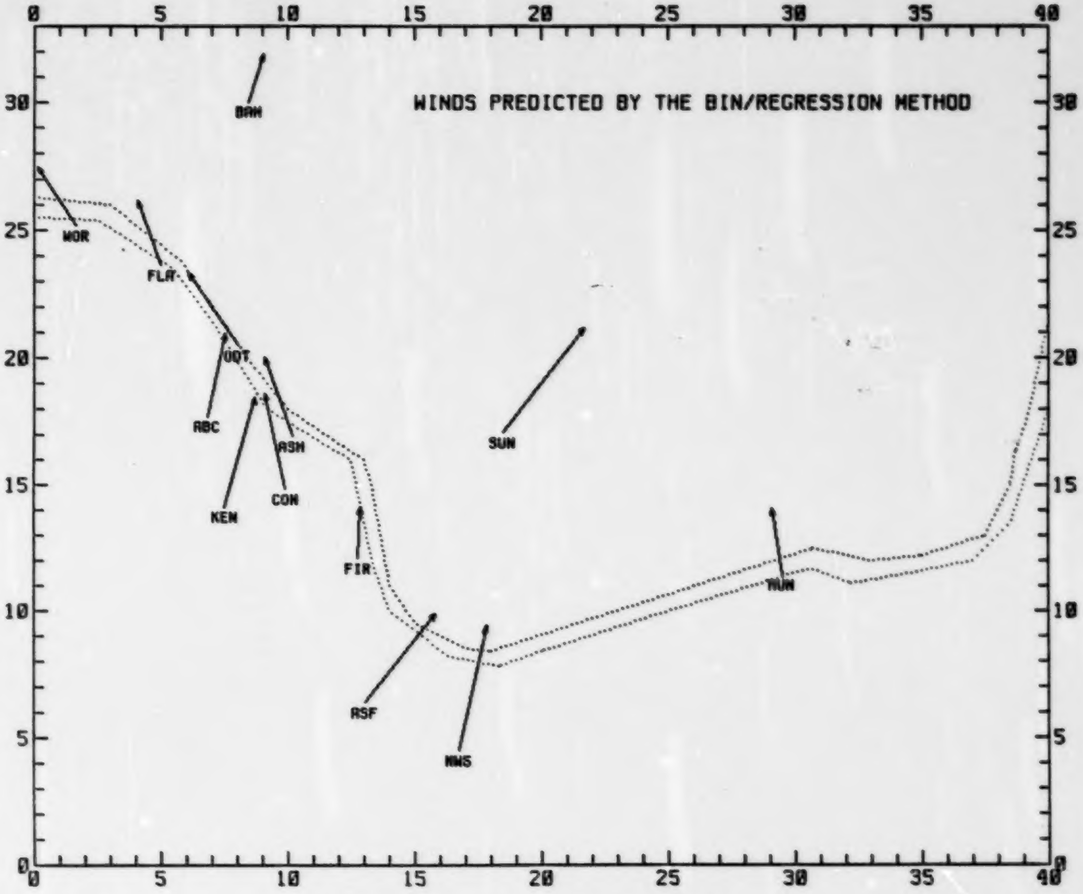
BIN 7 366 OCCURRENCES
WIND SPEED 1.10 AND UP
WIND DIRECTION 122.50 TO 142.50



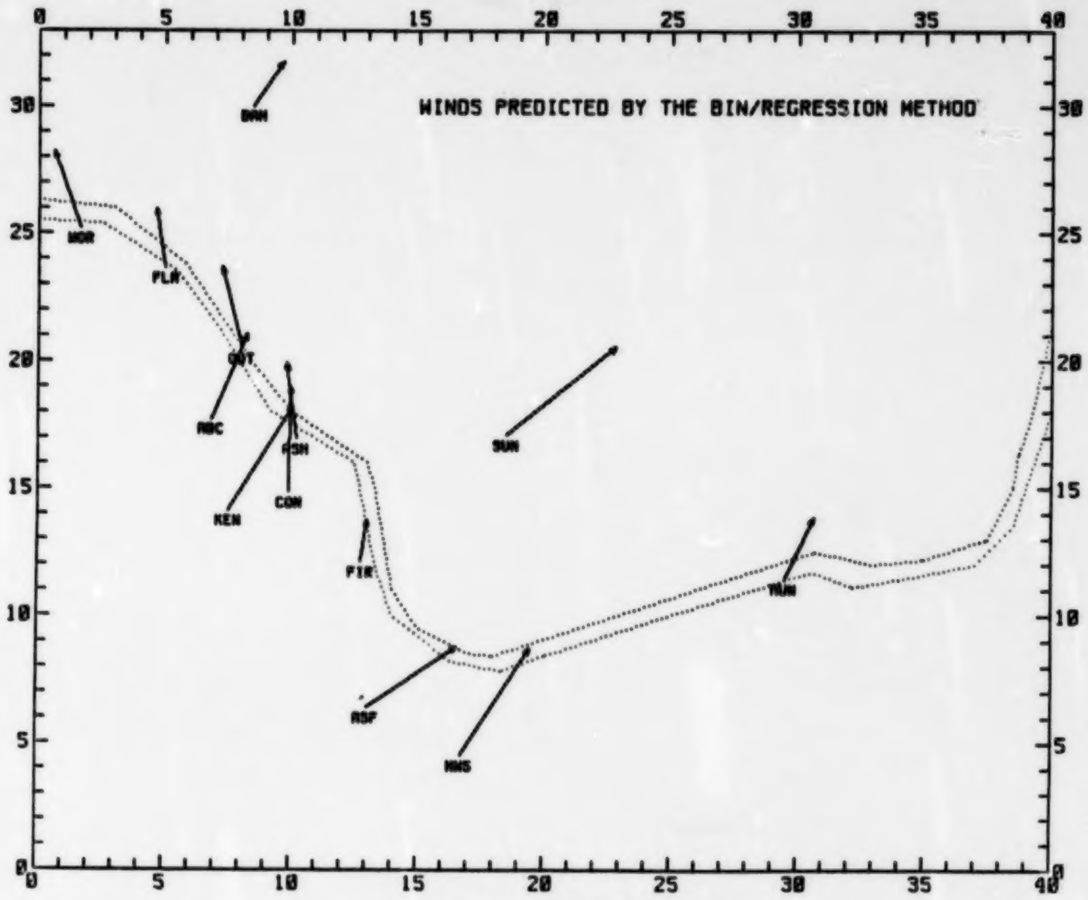
BIN 8 311 OCCURRENCES
WIND SPEED 1.10 AND UP
WIND DIRECTION 142.50 TO 162.50



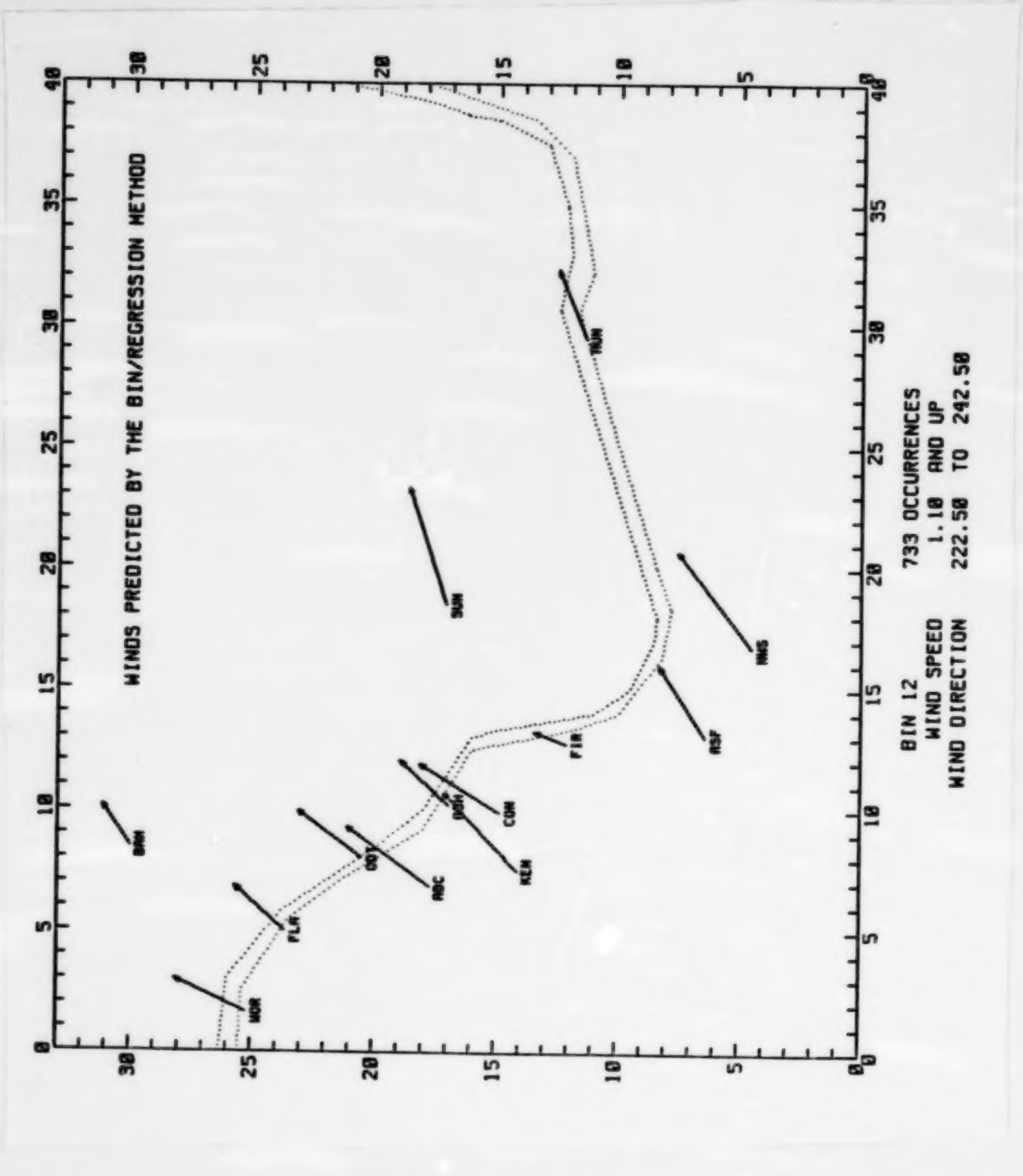
BIN 9 357 OCCURRENCES
WIND SPEED 1.10 AND UP
WIND DIRECTION 162.50 TO 182.50

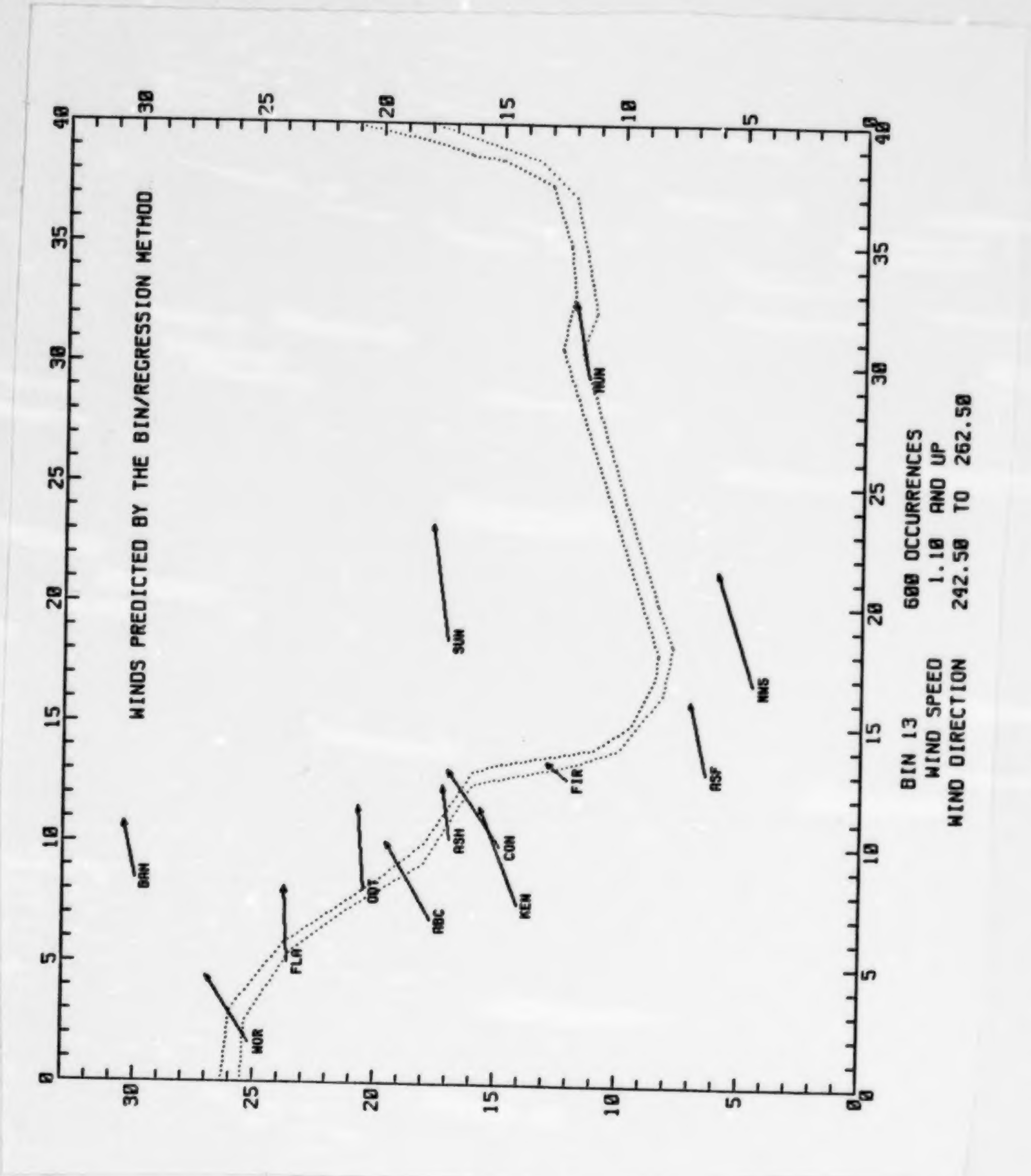


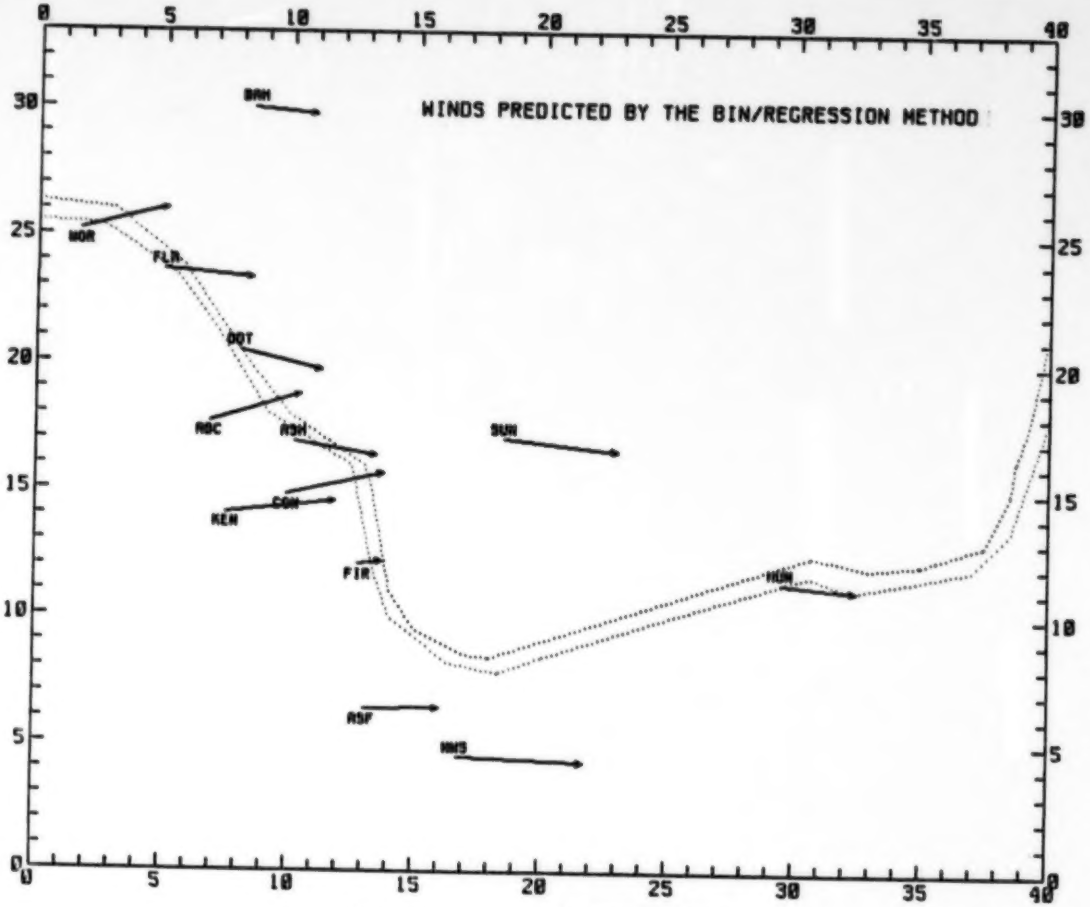
BIN 10 579 OCCURRENCES
WIND SPEED 1.10 AND UP
WIND DIRECTION 182.50 TO 202.50



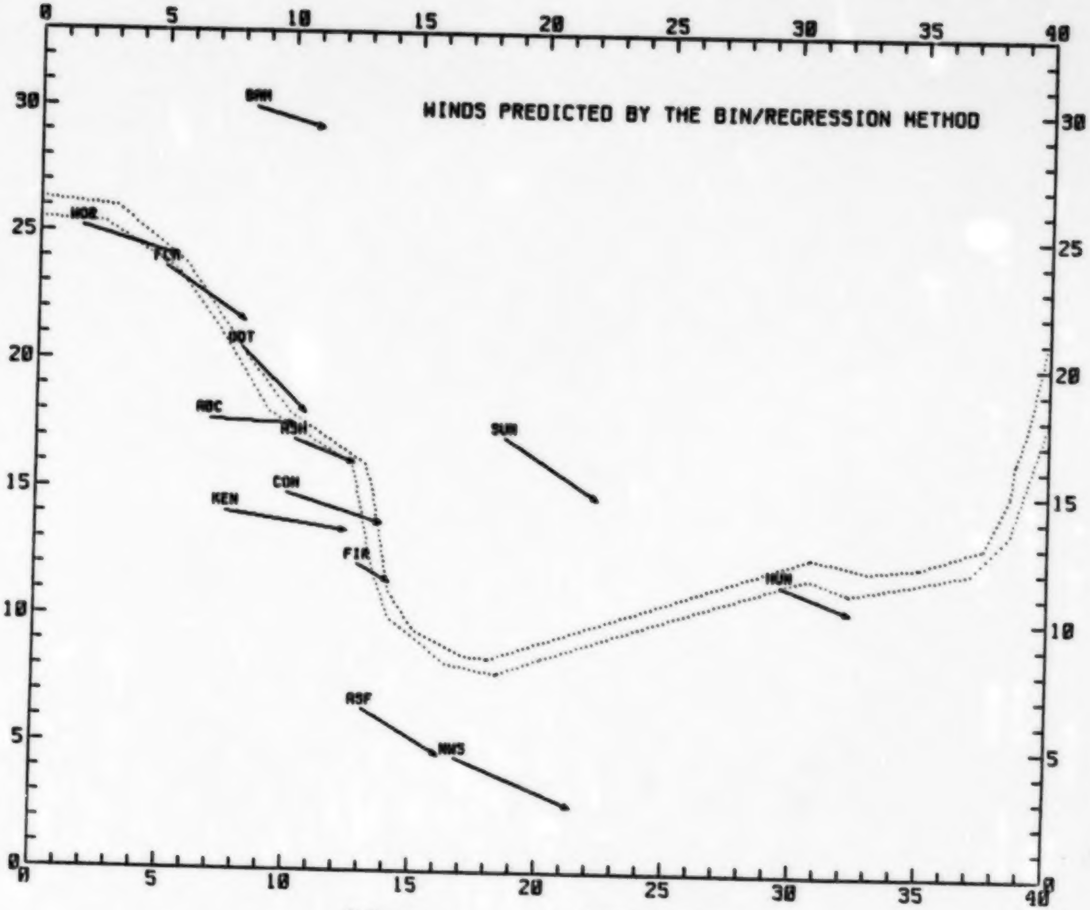
BIN 11 1064 OCCURRENCES
WIND SPEED 1.10 AND UP
WIND DIRECTION 202.50 TO 222.50


WINDS PREDICTED BY THE BIN/REGRESSION METHOD
0
5
10
15
20
25
30
35
40
WOR
FLA
BAN
ODT
ROC
KEN
DOH
CON
FIR
ASF
NNS
SUN
MUN
BIN 12 733 OCCURRENCES
WIND SPEED 1.10 AND UP
WIND DIRECTION 222.50 TO 242.50

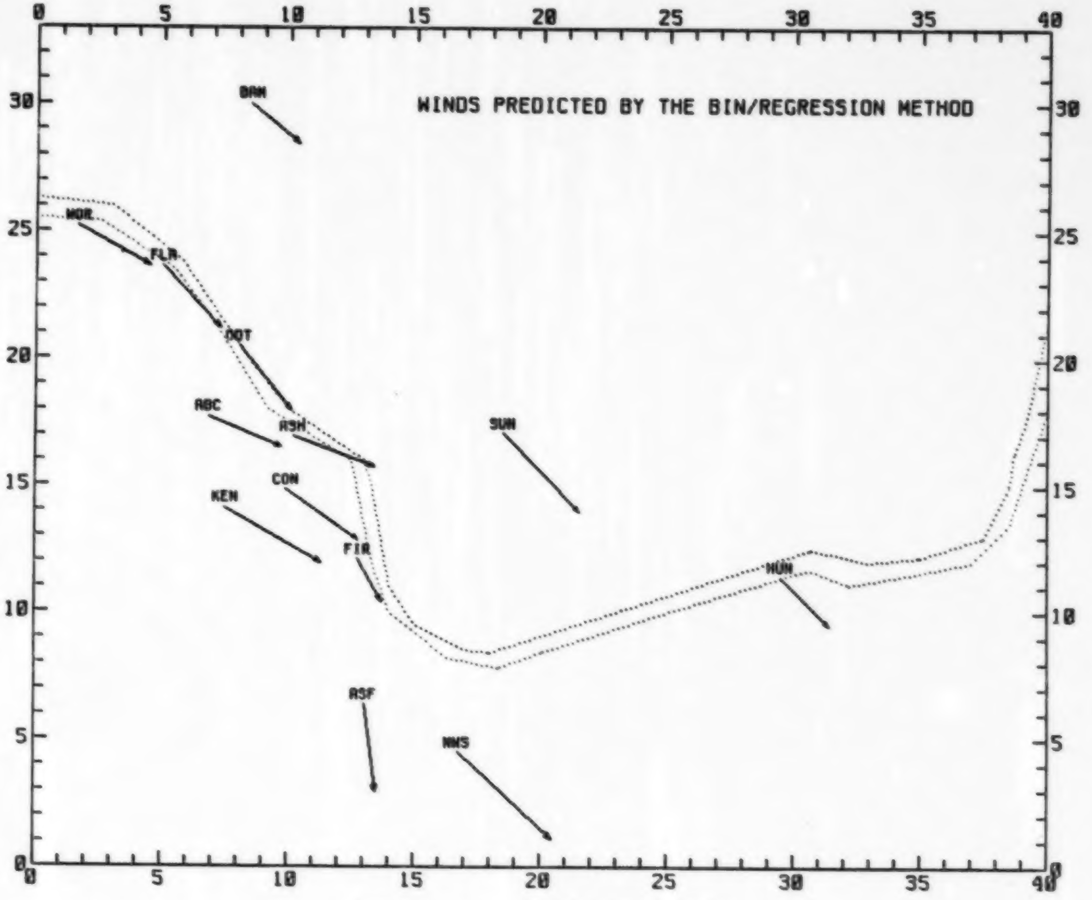

WINDS PREDICTED BY THE BIN/REGRESSION METHOD
BAN
WOR
FLA
ODT
ABC
ASH
CON
KEN
SUN
FIR
ASF
NWS
YUN
0
5
10
15
20
25
30
35
40
BIN 13 600 OCCURRENCES
WIND SPEED 1.10 AND UP
WIND DIRECTION 242.50 TO 262.50



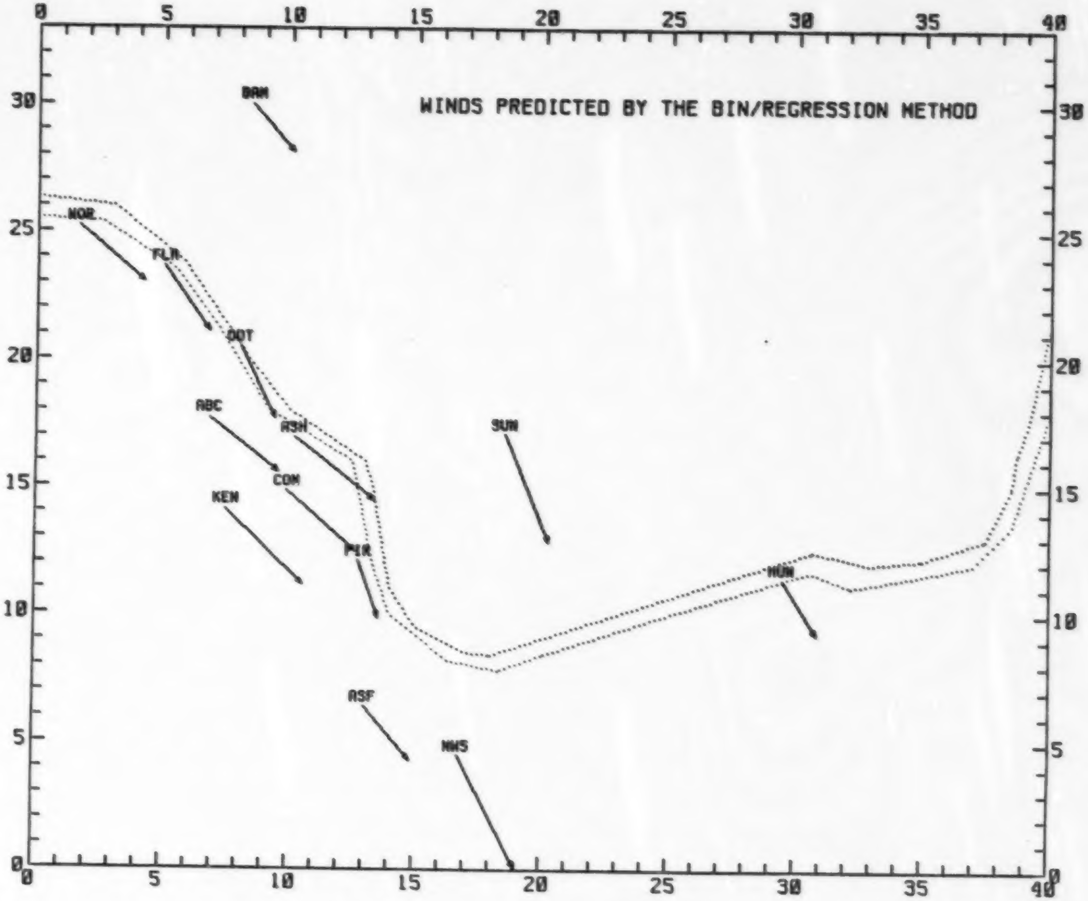
BIN 14 595 OCCURRENCES
WIND SPEED 1.10 AND UP
WIND DIRECTION 262.50 TO 282.50



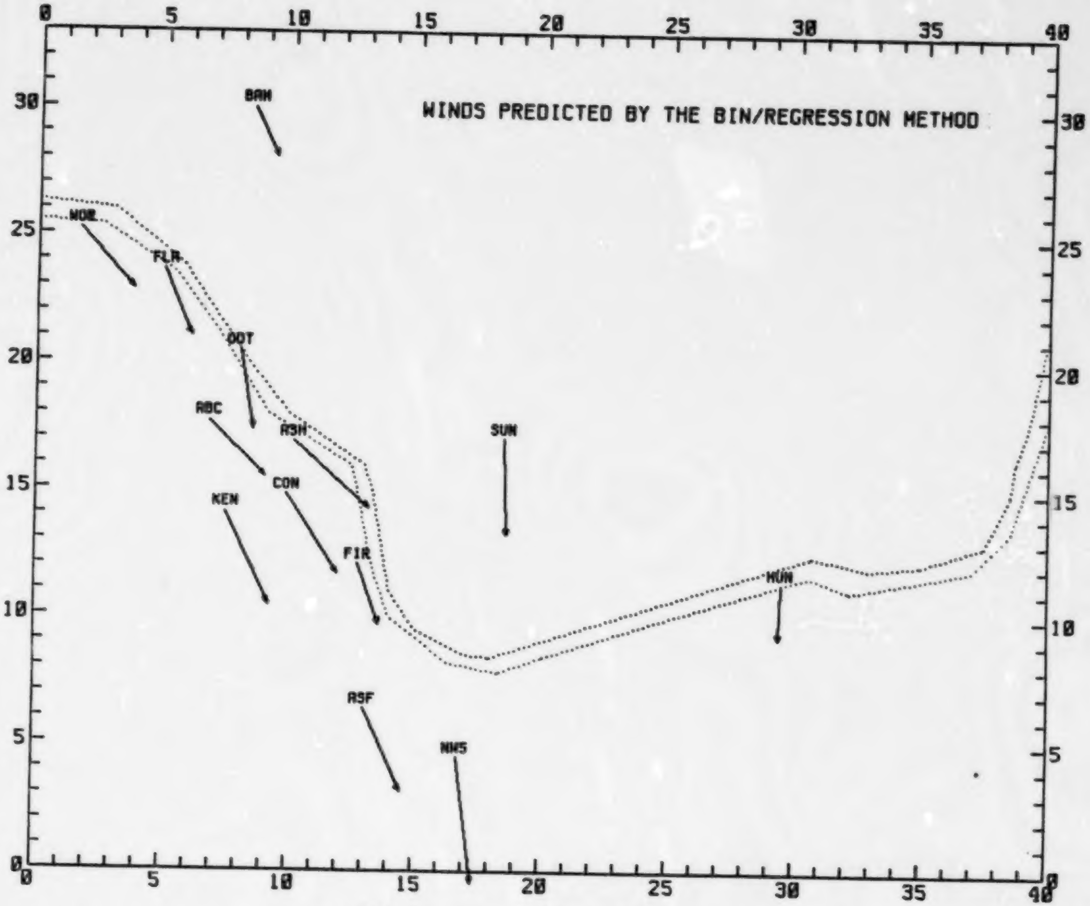
BIN 15 390 OCCURRENCES
WIND SPEED 1.10 AND UP
WIND DIRECTION 282.50 TO 302.50



BIN 16 376 OCCURRENCES
WIND SPEED 1.10 AND UP
WIND DIRECTION 302.50 TO 322.50



BIN 17 470 OCCURRENCES
WIND SPEED 1.10 AND UP
WIND DIRECTION 322.50 TO 342.50



BIN 18 421 OCCURRENCES
WIND SPEED 1.10 AND UP
WIND DIRECTION 342.50 AND UP

APPENDIX F

DETAILS OF RECOMMENDATIONS FOR FURTHER ANALYSIS

APPENDIX F

DETAILS OF RECOMMENDED ALTERNATIVE ANALYSES

ALTERNATIVE ANALYSES USING THE BIN/REGRESSION METHOD

There are two areas in which further analysis using the bin/regression method described in Section 3 may be profitable. First the stratification of the data using additional variables may improve results. Stratification by combined wind speed and direction has been analyzed and has not led to significant improvements over stratification by direction alone, because the linear relationship of the wind speeds takes into account much of the variation in speed. Stratification using variables such as season, day/night, or stability class should be more helpful. If any of these variables has a substantial influence on the results, we expect the effect to be nonlinear; therefore, stratification is suitable for examining this effect.

It would also be useful to redo the bin/regression analysis using network station data collected each hour in place of the hourly averaged values. This will give values that are commensurate with the NWS measurements and can provide information concerning the compatability of the NWS on-the-hour measurements with hourly averages.

THE USE OF A LINEAR MODEL IN THE COMPLEX PLANE FOR THE ANALYSIS OF WIND VELOCITIES

Viewing the Model in Complex, Rectangular, and Polar Coordinates

If u and v are the orthogonal components of the wind velocity vector, which we represent in the complex plane by $\zeta = u + iv$, with $i = \sqrt{-1}$, we can predict the wind velocity at a given station from the NWS wind velocity using a simple linear model in complex variables of the form

$$\hat{\zeta} = \alpha \zeta_{NWS} + \beta \quad ,$$

with

$$\alpha = a_1 + ia_2 \quad ,$$

$$\beta = b_1 + ib_2 \quad . \tag{F-1}$$

Thus, each change in ζ_{NWS} is matched by a proportionate change in angle and length of ζ. Returning to rectangular (u,v) coordinates, this model is

$$\hat{u} + i\hat{v} = (a_1 + ia_2)(u_{NWS} + iv_{NWS}) + (b_1 + ib_2) \quad ,$$

or

$$\hat{u} = a_1 \; u_{NWS} - a_2 v_{NWS} + b_1 \quad ,$$

$$\hat{v} = a_2 \; u_{NWS} + a_1 v_{NWS} + b_2 \quad . \tag{F-2}$$

We see that the complex linear model entails the fitting of four unknown real-valued parameters and is thus a constrained version of a general real-valued multivariate linear model requiring six real-valued parameters. In polar coordinates, (U, Θ), the model may be written as

$$\hat{U}\, e^{i\hat{\Theta}} = \hat{u} + i\hat{v} \quad ,$$

so that

$$U = (\hat{u}^2 + \hat{v}^2)^{1/2} \quad ,$$

$$\hat{\Theta} = \arctan \frac{\hat{v}}{\hat{u}} \quad , \tag{F-3}$$

where $\hat{u}$ and $\hat{v}$ are given by Equation (F-2). It can be seen that, for polar coordinates, the parameterization given by Equations (F-2) and (F-3) differs markedly from that of the 3-parameter polar coordinate model used in Section 3,

$$\tilde{U} = c\, U_{NWS} + d \quad ,$$

$$\tilde{\Theta} = \Theta_{NWS}\, \gamma \quad . \tag{F-4}$$

Moreover, a least-squares fit of Equation (F-1) could conceivably result in rather different $(\hat{U}, \hat{\Theta})$ values than a direct least-square fit of Equation (F-4).

Least-Squares-Fitting of Parameter Values by Minimizing the Sum of Modulus-Squared Residuals

Nearly all of the usual linear model results are directly applicable to the complex-valued case (Goodman, 1963 and Khatri, 1965). The most notable difference between real-valued and complex-valued linear models is that the assumption of normality takes a rather restrictive form in the complex case, requiring the real and imaginary parts to be independently normally distributed with common variance. The use of the least-squares criterion to fit parameters values to Equation (F-1) entails the minimization of

$$Q = \sum_{i=1}^{N} |\zeta_i - \hat{\zeta}_i|^2 \quad ,$$

$$= \sum_{i=1}^{N} |(\zeta_i - \hat{\mu}) - \alpha(\zeta_{NWS,i} - \hat{\mu}_{NWS}) + (\hat{\mu} - \alpha\hat{\mu}_{NWS}) - \beta|^2 \quad ,$$

$$= \sum_{i=1}^{N} \Big\{ |(\zeta_i - \hat{\mu}) - \alpha(\zeta_{NWS,i} - \hat{\mu}_{NWS})|^2 + |\hat{\mu} - \alpha\hat{\mu}_{NWS} - \beta|^2$$

$$+ 2\,\mathrm{Re}\,[(\zeta_i - \hat{\mu}) - \alpha(\zeta_{NWS,i} - \hat{\mu}_{NWS})]\overline{[\hat{\mu} - \alpha\hat{\mu}_{NWS} - \beta]} \Big\} \quad ,$$

$$= \sum_{i=1}^{N} |(\zeta_i - \hat{\mu}) - \alpha(\zeta_{NWS,i} - \hat{\mu}_{NWS})|^2 + N|\hat{\mu} - \alpha\hat{\mu}_{NWS} - \beta|^2 \quad , \qquad \text{(F-5)}$$

where

$$\hat{\mu} = \frac{1}{N}\sum_{i=1}^{N} \zeta_i \quad , \qquad \text{(F-6)}$$

and

$$\hat{\mu}_{NWS} = \frac{1}{N}\sum_{i=1}^{N} \zeta_{NWS,i} \quad . \qquad \text{(F-7)}$$

It can be shown that

$$\hat{\alpha} = \frac{\sum_{i+1}^{N} (\zeta_i - \hat{\mu})\overline{(\zeta_{NWS,i} - \hat{\mu}_{NWS})}}{\sum_{i=1}^{N} |\zeta_{NWS,i} - \hat{\mu}_{NWS}|^2} \quad , \qquad \text{(F-8)}$$

$$\hat{\beta} = \hat{\mu} - \hat{\alpha}\hat{\mu}_{NWS} \quad , \qquad \text{(F-9)}$$

minimize Q. Since the derivation of Equation (F-9) from (F-5) can be seen directly, we restrict our attention to the derivation of Equation (F-8). This is most easily demonstrated in vector format. Suppose that $\underset{\sim}{z}$ and $\underset{\sim}{w}$ are two complex-valued N-vectors and that we seek a complex-valued sclar, $\hat{\gamma}$, that minimizes

$$||\underset{\sim}{z} - \gamma\underset{\sim}{w}||^2 = \langle \underset{\sim}{z} - \gamma\underset{\sim}{w}, z - \underset{\sim}{w} \rangle$$

$$= \sum_{i=1}^{N} (z_i = \gamma w_i)\overline{(z_i - \gamma w_i)}$$

We claim that the minimizing value is

$$\hat{\gamma} = \langle \underset{\sim}{z}, \underset{\sim}{w} \rangle / ||\underset{\sim}{w}||^2$$

$$= \sum_{i=1}^{N} z_i \bar{w}_i / \sum_{i=1}^{N} |w_i|^2 \quad .$$

Note that

$$\langle \underset{\sim}{z} - \gamma\underset{\sim}{\hat{w}} , \underset{\sim}{w} \rangle = \langle \underset{\sim}{z}, \underset{\sim}{w} \rangle - \hat{\gamma}||w||^2 = 0 \quad ,$$

so that

$$||\underset{\sim}{z} - \gamma\underset{\sim}{w}||^2 = ||\underset{\sim}{z} - \hat{\gamma}\underset{\sim}{w} + (\hat{\gamma} - \gamma)\underset{\sim}{w}||^2$$

$$= ||\underset{\sim}{z} - \hat{\gamma}\, \underset{\sim}{w}||^2 + |\hat{\gamma} - \gamma|^2||\underset{\sim}{w}||^2 \quad ,$$

which is obviously minimized by taking $\gamma = \hat{\gamma}$. Letting

$$\utilde{z} = \zeta - \hat{\mu}\,\utilde{1} \quad ,$$

and

$$\utilde{w} = \utilde{\zeta}_{NWS} - \hat{\mu}_{NWS}\,\utilde{1} \quad , \qquad \text{(F-10)}$$

we obtain Equation (F-10).

Coherence--an Analogue of Squared Correlation That Measures Goodness of Fit

In the real-valued case, the sample correlation coefficient

$$\hat{\rho} = \frac{\sum_{i=1}^{N} (x_i - \overline{x})(y_i - \overline{y})}{\sum_{i=1}^{N} (x_i - \overline{x})^2 \sum_{i=1}^{N} (y_i - \overline{y})^2 \quad {}^{1/2}} \quad ,$$

is often used to judge the goodness of fit of the linear model

$$y_i = ax_i + b + e_i \quad .$$

We commonly assume that the errors e are random variables, having expected value zero and common variance

$$\sigma_e^2 \quad .$$

When the independent variable x is regarded as random, we usually make the additional assumption that it is independent of the error term e. Regarding y, x, and e as random variables, we thus obtain

$$\text{Var } y = \sigma_y^2 = a^2\sigma_x^2 + \sigma_e^2 \quad ,$$

and

$$\text{Cov }(x,y) = \text{Cov }(x, ax + b + e) \quad ,$$

$$= a \; {}_{x}^{2} \quad .$$

Thus

$$\rho = \frac{\text{Cov}(x, y)}{[\text{Var } x \cdot \text{Var } y]^{1/2}}$$

$$= \frac{a\,\sigma_x^2}{\sigma_x^2\,(a^2\sigma_x^2 + \sigma_e^2)^{1/2}} \quad ,$$

$$\rho^2 = \frac{a^2\sigma_x^4}{\sigma_x^2\,(a^2\sigma_x^2 + \sigma_e^2)} \quad ,$$

$$= \frac{a^2\sigma_x^2}{a^2\sigma_x^2 + \sigma_e^2} \quad ,$$

and

$$1 - \rho^2 = \frac{\sigma_e^2}{a^2\sigma_x^2 + \sigma_e^2} = \frac{\sigma_e^2}{\sigma_y^2} \quad .$$

That is, $1 - \rho^2$ measures the variance of the errors e relative to the variance of the dependent variable y. The closer ρ^2 is to unity, the smaller this relative magnitude of error is, and the better the model. In practice, we use the sample correlation coefficient to estimate this relative reduction in variance as $1 - \hat{\rho}^2$.

The complex analogue of the squared correlation coefficient is the coherence between two complex-valued random variables. The generalization from real to complex values is accomplished by writing

$$\text{Cov}(z, w) = E(z - \mu_z)\overline{(w - \mu_w)} \quad ,$$

so that

$$\text{Var } z = \text{Cov}(z, z) = E|z - \mu_z|^2 \quad .$$

The coherence between z and w is defined as

$$|\rho|^2 = \text{coh}(z, w) = \frac{|\text{Cov}(z, w)|^2}{[\text{Var } z \cdot \text{Var } w]} \quad .$$

The term coherency is often used for ρ (the complex value) itself.

As in the real-valued case, it can be shown that $1 - |\rho|^2$ measures the variance of the (complex-valued) error term relative to the variance of the dependent variable, e.g.,

$$1 - |\rho|^2 = \frac{\text{Var } \varepsilon}{\text{Var } \zeta} \quad ,$$

in the linear model

$$\begin{aligned} \zeta &= \xi + \varepsilon \\ &= \alpha\zeta_{NWS} + \beta + \varepsilon \quad . \end{aligned}$$

In terms of rectangular coordinates (u, v), we have

$$\begin{aligned} \text{Cov}(\zeta, \zeta_{NWS}) &= E(\zeta - \mu)\overline{(\zeta_{NWS} - \mu_{NWS})} \\ &= E\{(u - Eu)(u_{NWS} - Eu_{NWS}) + (v - Ev)(v_{NWS} - Ev_{NWS})\} \\ &+ i\,E\{(v - Ev)(u_{NWS} - Eu_{NWS}) - (u - Eu)(v_{NWS} - Ev_{NWS})\} \\ &= \text{Cov}(u, u_{NWS}) + \text{Cov}(v, v_{NWS}) \\ &+ i\,\{\text{Cov}(v, u_{NWS}) - \text{Cov}(u, v_{NWS})\} \quad , \end{aligned}$$

$$\text{Var} \quad = \quad \text{Var } u + \text{Var } v \quad ,$$

$$\text{and Var}_{\text{NWS}} \quad = \quad \text{Var } u_{\text{NWS}} + \text{Var } v_{\text{NWS}}$$

so that

$$|\rho|^2 = \frac{[\text{Cov }(u,u_{\text{NWS}}) + \text{Cov}(v,v_{\text{NWS}})]^2 + [\text{Cov}(v,u_{\text{NWS}}) - \text{Cov}(u,v_{\text{NWS}})]^2}{(\text{Var } u + \text{Var } v)(\text{Var } u_{\text{NWS}} + \text{Var } v_{\text{NWS}})}$$

is our figure of merit.

THE POTENTIAL USE OF LAGGED RELATIONSHIPS IN PREDICTING STATION WIND VELOCITIES

So far, we have discussed the use of the wind velocity measured at the NWS station during a given hour to predict that at some other station using a linear model. In the previous section, for example, we considered a linear model expressed in complex variables:

$$\xi(g) = \alpha \, \zeta_{\text{NWS}}(t) + \beta \qquad \text{(F-11)}$$

Here we have explicitly included the time parameter t to denote the given hour. Note that this is a simultaneous linear model, i.e., the station prediction $\xi(t)$ at time t depends on the NWS velocity $\zeta_{\text{NWS}}(t)$ measured at the same time t and not at any other time. An important extension of this simultaneous linear model is a linear model involving NWS measurements at times other than the hour of prediction. A simple example of such a lagged linear model is

$$\xi(t) = \frac{1}{2} \zeta_{\text{NWS}}(t) + \frac{1}{2} \zeta_{\text{NWS}}(t - 1) \quad , \qquad \text{(F-12)}$$

in which $\xi(t)$ is the average of the NWS measurements at times t and t - 1. If we allow for some other linear combination of these measurements to form the prediction, we have the following generalization of Equation (F-12)

$$\xi(t) = \alpha(0) \, \zeta_{\text{NWS}}(t) + \alpha(1) \zeta_{\text{NWS}}(t - 1) + \beta \quad . \qquad \text{(F-13)}$$

The notation here is meant to indicate that coefficient $\alpha(0)$ applies to the NWS velocity measured at a time lag of 0 hours (i.e., measured during the same hour as the hour of prediction), whereas $\alpha(1)$ applies to the NWS velocity measured at a time lag of 1 hour (i.e., measured 1 hour previous to the hour of prediction). The prediction $\zeta(t)$ in Equation (F-13) is said to be a linearly filtered version of $\zeta_{NWS}(\cdot)$. In more general form, such models are written as

$$\zeta(t) = \sum_{j=1}^{J} \alpha(u_j)\, \zeta_{NWS}(t - u_u) + \beta \quad , \qquad \text{(F-14)}$$

Where the j lags, $u_1, u_2, \ldots, u_j$, are chosen to optimize the prediction by some criterion (usually least squares). Note that the NWS velocity measured at some hour in advance of the hour of prediction may be useful in predicting $\zeta(t)$. This corresponds to the use of $\zeta_{NWS}(t - u)$ with negative lag u. Note also that lagged linear models could be used with wind velocity coordinate representations other than the complex value representation.

Assessing the Value of the Introduction of Lagged NWS Measurements

One technique for determining which, if any, lags to use in Equation (F-14) is that of stepwise regression. Conceptually, this amounts to the construction of lagged NWS velocities so that for each hour, t, we have the station variable, $\zeta(t)$, as well as several lagged NWS variables, $\zeta_{NWS}(t - u)$, for a range of lags, u. In this scheme, the variables at each hour, t, are

$$\zeta(t),\ \zeta_{NWS}(t - U),\ \zeta_{NWS}(t - U + 1), \ldots,\ \zeta_{NWS}(t),$$

$$\zeta_{NWS}(t + 1), \ldots,\ {}_{NWS}(t + U) \quad . \qquad \text{(F-15)}$$

The idea is to select some maximal lag U and then employ ordinary stepwise regression to enter, one at a time, those independent variables with coefficients significantly distinct from zero that most reduce the residual variance.

There are other time series techniques for assessing the likely reduction in residual variance due to the introduction of lagged variables. These techniques entail the examination of certain characteristics of the two time series $\zeta(t)$ and $\zeta_{NWS}(t)$, namely, the cross-correlation function (in the time domain) and the coherence, phase and transfer function (in the frequency domain).

Methods of Choosing a Particular Time Series Model

Two widely used approaches to model selection and parameter fitting are the time-domain, or Box-Jenkins method and the frequency domain method. In the former, the patterns of autocorrelation, partial autocorrelations, and cross-correlations are examined, and a model is selected on the basis of these patterns. Coefficients are fit by means of linear or nonlinear least-squares. In the latter approach, the frequency domain transfer function is Fourier-transformed to produce a prescribed number of coefficients. Computer programs are available for both approaches; however, some modification would be required for the treatment of wind velocities represented by complex numbers.

Missing Values

Missing values require more attention in the use of lagged linear models than in the case of simultaneous linear models. Fortunately, few NWS measurements are missing and most of the other station measurements are fairly complete for certain months (these months vary from one station to the next). The missing values occurring within a month's data can either be interpolated or treated using special time series techniques (e.g., Bloomfield, 1970; Jones, 1980).

USE OF PRINCIPAL COMPONENT ANALYSIS TO OBTAIN PARSIMONIOUS LINEAR STATISTICAL MODELS

So far, we have treated each station individually when discussing the prediction of station wind velocities using the NWS wind velocity. Consider now the s-vector $\underset{\sim}{\zeta}$ representing wind velocities at s stations and the corresponding vectors $\underset{\sim}{\alpha}$, $\underset{\sim}{\beta}$ of slope and intercept coefficients, respectively. Using this vector notation, we can write the station regression equations collectively as

$$\zeta = \underset{\sim}{\alpha}\,\zeta_{NWS} + \underset{\sim}{\beta} + \epsilon \tag{F-16}$$

or as

$$\underset{\sim}{\zeta} = \underset{\sim}{\alpha}\,(\zeta_{NWS} - \mu_{NWS}) + \underset{\sim}{\mu} + \epsilon$$

where μ_{NWS} and $\underset{\sim}{\mu}$ represent long-term wind velocity averages. The analysis presented in Section 3 tested and rejected the hypothesis that $\underset{\sim}{\alpha} = \underset{\sim}{0}$. Having obtained a statistical vote of confidence for the use of slope coefficients $\underset{\sim}{\alpha}$, we would typically use those parameter values $\underset{\sim}{\hat{\alpha}}$ obtained by a least-squares fit. This choice between abandonment of the use of $\underset{\sim}{\alpha}$ or the adoption of $\underset{\sim}{\hat{\alpha}}$ amounts to choosing between a zero dimensional model and a full dimensional model for the set of predicted mean deviations (considering the wind velocities predicted for N consecutive time intervals at a given station as one vector in an N-dimensional space). There is, however, a position intermediate to abandonment of $\underset{\sim}{\alpha}$ altogether and the adoption of $\underset{\sim}{\alpha}$. This intermediate choice entails the use of principal component analysis and the selection of a linear model whose dimension is between 0 and s, the total number of stations.

Briefly, the use of principal components may be described in this context as follows:

1) form an eigenvalue/eigenvector decomposition of the sample covariance matrix of wind velocity mean deviation crossproducts between stations:

$$\hat{\Sigma}\,\underset{\sim}{\zeta} = U\,D\,U^{*} \qquad \text{(F-17)}$$

$$\text{with } U = (\underset{\sim}{u}_1, \cdots, \underset{\sim}{u}_s)$$

$$D = \operatorname{diag}\,[d_1, \cdots, d_s]$$

$$\text{and } d_1 \geq d_2 \geq \cdots \geq d_s \geq 0 \quad ;$$

2) Statistically test eigenvalues d_1, d_2, ... to determine the smallest eigenvalue d_p significantly distinct from zero; this determines the number p of principal components to be used in the model, and thus the dimension of the model; distinguish the first p eigenvectors using matrix $U^{(p)}$ defined as

$$U^{(p)} = (\underset{\sim}{u}_1, \underset{\sim}{u}_2, \cdots, \underset{\sim}{u}_p, \underset{\sim}{0}, \cdots, \underset{\sim}{0}) \quad ; \qquad \text{(F-18)}$$

3) For each time interval, form the vector $\underset{\sim}{\eta}$ of principal components given by

$$\underset{\sim}{\eta} = U^{*}\,\zeta$$

and distinguish the first p components using vector $\underset{\sim}{\eta}^{(p)}$

$$\underset{\sim}{\eta}^{(p)} = (\eta_1, \eta_2, \cdots, \eta_p, 0, \cdots, 0)' \quad ; \qquad \text{(F-19)}$$

$$\underset{\sim}{\eta}^{(p)} = \underset{\sim}{\gamma}^{(p)} \zeta_{NWS} + \underset{\sim}{\delta}^{(p)} + \underset{\sim}{\phi}^{(p)} ,$$

yielding predicted principal components

$$\hat{\underset{\sim}{\eta}}^{(p)} = \hat{\underset{\sim}{\gamma}}^{(p)} \zeta_{NWS} + \hat{\underset{\sim}{\delta}}^{(p)} ; \qquad \text{(F-20)}$$

5) Construct predictions $\hat{\underset{\sim}{\xi}}^{(p)}$ in the original coordinate system by rotating the vector $\hat{\underset{\sim}{\eta}}^{(p)}$ of predicted principal components:

$$\hat{\underset{\sim}{\xi}}^{(p)} = U \hat{\underset{\sim}{\eta}}^{(p)} .$$

The motivation for using this procedure is that we are using the observed covariance structure of station wind velocities to constrain the predictions, with the aim of enhancing their reliability (i.e., reducing the total mean squared error of prediction).

EVALUATING THE STATISTICAL RELIABILITY OF PREDICTED WIND VELOCITIES USING CROSS-VALIDATION TECHNIQUES

Standard methods for evaluating the goodness of fit of a statistical model to actual data are based on an examination of the residuals (observed value minus predicted value). It has been pointed out, however, that the same set of data is being used twice; first to fit model parameters and then to evaluate goodness of fit. This is taken into account in the theory of testing statistical hypotheses (e.g., that the underlying slope coefficient for predicting wind speed is zero) but it is often overlooked when residuals are used as indicators of the predictive performance of the fitted model. In fact, the fitted model can be expected to perform better, in general, using the data from which it was derived than using a new set of data. It has been proposed (see Efron, 1982) that model parameters be estimated from one portion of the data, and that the predictive ability of the fitted model be evaluated using a separate portion of the data. This method, called cross-validation, is a more reliable way to gauge the size and distribution of likely errors when predicting the values of variables (e.g., station wind velocities prior to 1980) by applying the fitted model to a new data set of independent variables (e.g., NWS wind velocities prior to 1980).

The computational effort required for cross-validating a statistical model depends on the model, the goodness of fit criterion, and the specific method of cross-validation. One such method, called PRESS (predicted residual sum of squares), requires little additional computation when applied to linear models such as we have considered for wind field predictions. Similar efficient methods of cross-validation exist for time series models. We therefore recommend these methods for future evaluations of the reliability of predicted wind fields.